Tablets & Interne

Mobile Sl

GoPhor

Wireless Home

Overage: If you exceed the amount of data included in your plan during your billing period, additional data will automatically be provided in increments of 250MB at $14.99 per 250MB on a 250MB plan or 1GB at $10 per 1GB on the 3GB and 5GB plans. Data allowances, including overages, must be used in billing period provided or will be forfeited. **Data:** Tethering is allowed with compatible devices only with 5GB plan. Data used by devices connected to a tethering device or mobile hotspot is deducted from the data allowance. **Wi-Fi:** Access to AT&T Wi-Fi Basic for Wi-Fi enabled compatible devices is included. See **www.attwifi.com (http://www.attwifi.com/)** for additional restrictions and hotspot locations. Wi-Fi Basic terms and conditions apply. International Wi-Fi access is not included. **International Roaming: Monthly plan prices do not apply to data usage while roaming.** If roaming outside U.S., international data rates will be charged at $0.015 per KB (Canada) and $0.0195 per KB (all other international). **General Wireless Service Terms: Subject to Wireless Customer Agreement.** Activation or upgrade fee (up to $40) per line &deposit may apply. An activation fee may be charged if converting from a prepaid or session-based plan or when activating an additional device/line. Credit approval may be required. **Other Monthly Charges:** Apply per line and may include taxes, federal and state universal service charges, a Regulatory Cost Recovery Charge (up to $1.25), a gross receipts surcharge, an Administrative Fee, and other government assessments which are not government-required charges. **Pricing, fees, options, restrictions and terms subject to change and may be modified, terminated, or discontinued at any time without notice**Coverage and service not available everywhere. Other restrictions apply and may result in service termination. For full service terms and conditions, visit **att.com/wirelessterms (http://www.att.com/wirelessterms)**.

EXHIBIT SEPARATOR PAGE

AT&T Mobile Share Value® Plans

With unlimited talk and text with shared data on up to 10 devices.

Now with Rollover Data℠ – What you don't use this month, rolls over to next month.*

[illegible]	Great value for single lines				Great value for families					
Mobile Share Value with Unlimited Talk & Text	300MB	1GB	3GB	6GB	10GB	15GB	20GB	30GB	40GB	50GB
per month	$20	$25	$40	$70	$100	$130	$150	$225	$300	$375

Overage: $20/300MB on 300MB plan, $20/500MB on 1GB plan, and $15/GB on all other plans. **Overage data must be used in the billing period it is provided and does not roll over.**
***Rollover Data:** Unused data from your monthly plan allowance carries over for one billing period starting on January 25, 2015. Rollover Data automatically expires after one billing period or with any plan change, and is consumed after all other data allowances. Mobile Share Data plans are excluded.

[illegible]	[illegible]	[illegible]
No Annual Service Contract[1] (AT&T Next℠, bring your own, purchase at full price, and month-to-month contract)	$25/mo	$15/mo
2-year Agreement[1]	$40/mo	$40/mo

[1]2-year Agreement access charge is $40/mo. For plans 10GB or higher, AT&T customers with smartphones on 2-year agreements prior to February 2, 2014, are eligible for the $15/mo. access charge. For plans 3GB to 6GB, AT&T customers with smartphones on 2-year agreements prior to March 9, 2014, are eligible for the $25/mo. access charge. **Upgrade: If upgrading to a smartphone on a 2-year wireless agreement you will lose this discounted access charge for that line. To receive this monthly discount, upgrade with AT&T Next or pay the full purchase price for your new smartphone.**

Add more devices to your plan

Basic & Messaging Phones	Tablets & Connected Devices	Connected Wearables	Laptops, LaptopConnect, Mobile Hotspot Devices & Netbooks	AT&T Wireless Home Phone	AT&T Wireless Home Phone & Internet[2]
Shared Data and Unlimited Talk & Text	Shared Data	Shared Data and Unlimited Talk & Text (to/from AT&T connected wearable)	Shared Data	Unlimited Nationwide Calling (no text or data)	Shared Data and Unlimited Nationwide Calling
300MB - 6GB $20/mo or 10GB - 50GB $15/mo	$10/mo	$10/mo	$20/mo	$20/mo	$30/mo

[2]May only be added to plans with 10GB or more of shared data.

No roaming or long distance charges nationwide.

Map approximates coverage. Coverage and service not available everywhere.

Mobile Share Value Plans Pricing: Prices are for service only include monthly plan charge & monthly access charge per device. **Discounted Access Charge:** Access charges for smartphone lines on no annual service contracts (AT&T Next℠ bring your own, pay full price or month-to-month) are discounted up to $25 per month when compared to smartphone lines on new 2-year agreements. The discount will be $25 per smartphone line on plans 10 GB and higher, and $15 for plans less than 10GB. For plans 10GB or higher, customers with smartphones on 2-year agreements prior to February 2, 2014, also are eligible for the $15 per month discounted access charge. For plans 3GB to 6GB, customers with smartphones on 2-year agreements prior to March 9, 2014, also are eligible for the $25 per month discounted access charge. This discount is available as long as you keep your phone. **Upgrade: If upgrading to a new smartphone, the discounted access charge is only available via AT&T Next or when you bring your own smartphone or buy a new smartphone at full price. If you upgrade to a new 2-year agreement, the discount is lost for that smartphone line. Data:** If usage exceeds data allowance (including available Rollover Data) during your billing period, you will be automatically provided 300MB for $20 on the 300MB plan, 500MB for $20 on the 1GB plan, or 1GB for $15 on all other plans. Unless otherwise specified, all data allowances, including overages and Rollover Data, must be used in the billing period they are provided. All prices are billed monthly and are valid for use in the U.S. only. Tethering and Mobile Hotspot use for up to five (5) simultaneous devices. Authorized users on the account may temporarily suspend data access for each device using the Mobile Share Value Plan. Data access will be restored at the beginning of the next billing cycle. Monthly charges however, will continue to apply. **Rollover Data℠: Only available with Mobile Share Value plans.** Unused data from the monthly plan allowance rounds up to the nearest MB and carries over for one billing period starting on January 25, 2015. **Unused Rollover Data automatically expires after one billing period or with any plan change (such as changing data amounts or termination).** Unused overage data does not roll over. Rollover Data is always consumed last, after your other data allowances. Unused Rollover Data is not redeemable for cash or credit and is not transferable including to other Mobile Share Value groups on your account. Mobile Share and Mobile Share Data-only plans are excluded. **Eligibility:** Available to consumers and IRUs. For full service terms and conditions for consumers and IRUs, please see a sales representative, or visit att.com/wirelessterms. **Devices:** Sold separately. AT&T Next and other device purchase costs additional. **Device Limits:** 10 per plan for consumers & IRUs. Limit 4 financed devices per wireless account may apply. **Unlimited Talk & Text:** For phones and wearables only. Includes domestic calls & messaging. **Unlimited International Messaging:** Includes messaging from the U.S., Puerto Rico and the U.S. Virgin Islands to more than 190 countries for text messages and 120 countries for picture & video messages. Capabilities vary by country. AT&T may add, change and remove included countries at its discretion without notice. Visit att.com/text2world for details. **Messaging:** applies only to AT&T's Short Messaging Service (SMS) and Multimedia Messaging Service (MMS) and not to any other messaging services or applications. Messages are for direct communication between phones and must originate from your phone. Messages sent to tablets, laptops, or other connected devices are excluded. Messages sent through applications may incur data charges. Service may be terminated or restricted for tethered messaging or misuse. **Wireless Home Phone ("WHP"):** is a wireless voice service (CMRS) & includes nationwide calling. **Wireless Home Phone and Internet ("WHPI"):** is a CMRS & mobile broadband Internet access service. Includes nationwide calling & shared data. Plan 10GB or higher required. **WHP & WHPI General:** Messaging excluded. For emergency calls, provide location to 911 operator. Devices have a backup battery but landline equip. w/separate power will not place/receive calls (including 911) during outage. Not compatible with landline-dependent services like medical alert monitoring systems. Other Compatibility limitations apply. For WHP details visit att.com/getwirelesshomephone and att.com/getwirelesshome. **Connected Wearables:** a wireless phone designed to be worn that is capable of making/receiving calls without being connected to another wireless device. For a list of eligible devices visit www.att.com/wearableslist. **IRU:** The service discount described in your organization's AT&T business agreement is available only for qualified Mobile Share Value Plans of 1GB or higher, and the service discount applies only to the monthly service charge for the data allotment, not to any monthly device access charges. See att.com/mobilesharevalue or a store representative for more plan details.

General Wireless Service Terms: Subject to Wireless Customer Agreement. Activation/upgrade fee per line (up to $45) and deposit may apply. A fee may be charged if convert from a prepaid or session-based plan or when activate an additional device. Credit approval may be required. AT&T reserves the right to suspend or terminate service to your account, place any non-complying device on an appropriate plan, and/or add any other required element of a plan. **Other Monthly Charges:** Apply per line and may include taxes, federal/state universal service charges, a Regulatory Cost Recovery Charge (up to $1.25), a gross receipts surcharge, an Administrative Fee, and other government assessments which are not government required charges. Monthly access charge per device may not be eligible for discounts. Other restrictions apply and may result in service termination. **Pricing and terms subject to change and may be modified, discontinued or terminated at any time without notice.** Other restrictions apply and may result in service termination. **Coverage:** Check coverage in your area at wireless.att.com/coverageviewer. Your phone's display does not indicate the rate you will be charged. Please review your coverage map for areas included in and out of plan.

att.com/wireless
888.MOBILITY

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For deaf/hard-of-hearing customers: (TTY) 866.241.6567

Questions on accessibility by persons with disabilities: 866.241.6568

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EXHIBIT SEPARATOR PAGE

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The MORE Everything Plan℠

Our best plan on the network you can trust.

10 gigs for $80 a month

and $15 a month per smartphone line.

Plus Taxes and fees. Smartphone device payment activation req'd.

VIEW ALL THE DATA OPTIONS

Here's What You Get

Unlimited Talk & Text

Don't count minutes or worry about overages.

Flexible Data Packages

Share your data with up to 10 devices and change it at any time.

A Rewarding Loyalty Program

There are more ways to earn Smart Rewards points on The MORE Everything Plan.

25 GB Cloud Storage

Store photos, contacts and more with the Verizon Cloud App.

NFL® Mobile

Watch football on the go with live local and primetime games.

International Texting

Send unlimited texts from the US to over 200 countries worldwide.

2 Steps to Building Your MORE Everything Plan

Step 1. Choose your shareable data.

Your monthly account access is the cost of your shared data with unlimited talk & text.

VOICE & DATA PRICING DATA ONLY PRICING

6 GB	8 GB	10 GB	12 GB	14 GB	16 GB
-	-	-	-	-	-
$40*	$50*	$60*	$70*	$80*	$90*

*Monthly Account Access

What you can do with 10 GB

30 streaming video or 2,000 hrs turn-by-turn navigation or 30,000 webpages or 130,000 emails

All statistics based on average usage and file sizes.

+

Step 2. Connect your devices.

Your monthly line access is the cost for each device that is permitted to use the service allowances included in your plan.

Smartphones

Your monthly line access cost varies depending on how you choose to pay for your device.

2-YEAR CONTRACT	MONTHLY DEVICE PAYMENT FULL PRICE OR BRING YOUR OWN SEE HOW DEVICE PAYMENT WORKS WITH THE MORE EVERYTHING PLAN ›	
All Data Allowances $40 mo. line access per smartphone.	Shared Data 6 GB & Up $15 mo. line access per smartphone.	Shared Data 4 GB & Under $25 mo. line access per smartphone.

Tablets	Basic Phones	Hot Spots	Connected Devices
$10 mo. line access per device	$20 mo. line access per device	$20 mo. line access per device	$5 mo. line access per device

Start Shopping with The MORE Everything Plan

Shop for Devices

Choose the devices you want on your plan.

Shop Now

Bring Your Own Device

Already have a device? Activate it today.

Activate Your Device

Frequently Asked Questions

READ FAQS ›

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Sign Up

Connect with us

By entering your email address and submitting this form, you agree to receiving information, offers and promotions regarding Verizon Wireless products and services. You acknowledge being at least 13 years of age.

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- LG
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Plans, Deals & More
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- Deals & Special Offers
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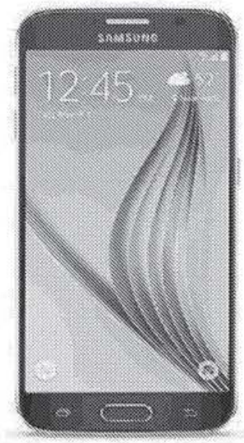
EXHIBIT SEPARATOR PAGE

Featured phones

- 

Samsung Galaxy S6
- 

LG G4

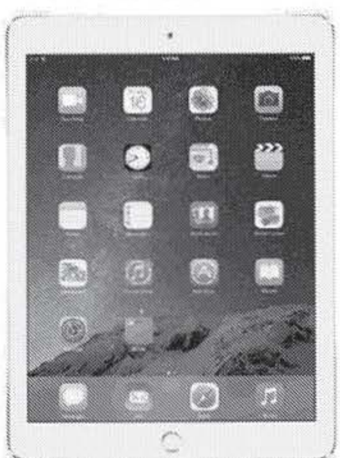
- 

HTC One M9

- Shop all tablets & internet devices
- Bring your own tablet

Featured devices

- 

LG G Pad F 8.0
- 
Apple iPad Air 2

- Samsung Galaxy Tab® S
- Shop all accessories

Most popular categories

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- Cases

- Wearable Tech

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Two days. One extreme discount.

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Shop now

Qualifying rate plan required.

- Plans

- Individual plans
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- Mobile Internet plans
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Now get three countries for the price of one.

Unlimited calls and text to and from the U.S., Mexico, and Canada to any phone-plus 4G LTE data-just like at home.

Learn more

Device, network, and coverage impact experience and speeds, which vary.

MEXICO
CANADA
AND THE U.S.

AMERICA'S
FASTEST
4G LTE
NETWORK

Check coverage

Enter a valid address CHECK COVERAGE
Please enter a valid address
The map cannot display this address. Try again.
Learn about our coverage

Expand your coverage to Mexico and Canada at no extra charge

Check it out

Maps with verified customer connection data

Check coverage

An expanded network

Call and text with WiFi

- Why T-Mobile
- Network

- Upgrade
- Simple Choice Plan
- Wi-Fi Calling
- Music Freedom
- Data Stash

Trapped by contracts and phone payments?

Stuck with your current carrier? T-Mobile can set you free. We'll pay off your phones or tablets with a trade-in credit and Visa® Prepaid Card when you trade them in–every last cent. Stuck in annual service contracts? We've got those covered, too. So why wait? Ditch your carrier and their switching fee today. See requirements.

Learn More

- Designed Data Strong
- Check Your Coverage
- T-Mobile Test Drive

Get the Data Strong™ network

With T-Mobile, you'll experience more data capacity than any other major national carrier. And only T-Mobile offers unlimited 4G LTE data on the fastest nationwide 4G LTE network.

Learn more

Fastest LTE Network: Based on download speeds. **Capacity Claim Basis**: congestion experienced; per customer.

Find closest store

Enter City and State, or Zip C Find Stores Enter City and State, or Zip Code
Sorry. We were not able to find any T-Mobile stores near that ZIP code.
Invalid Country
Please enter a city, state, or zip code.
Set this location as the default one
Set this location as the default one
This has been set as your location.

Additional locations
Search Find Search
Login BACK TO MY T-MOBILE BACK TO MY T-MOBILE Sign up

- Pay my bill
- Add a new line
- Upgrade my phone
- Change plan or services
- Get support

- Store Locator My T-Mobile Pay my bill Add a new line Upgrade my phone Change plan or services Get support Phones Tablets & Devices Accessories Deals Bring Your Own Phone Plans Why T-Mobile Network Coverage

We're breaking the rules of prepaid.

T-Mobile changed everything you know about wireless. Now, from plans to phones to how you pay—we're flipping the script on prepaid.

Why would you settle for second-rate prepaid wireless?

Say goodbye to slow data speeds, spotty networks, and second-rate phones. T-Mobile is bringing the best in wireless to prepaid.

Introducing Simply Prepaid™ from T-Mobile. 4G LTE data and unlimited talk and text for just $40 per month. Choose from three great plans:

- $40 / month for unlimited data, talk, and text on our network + up to 1GB of 4G LTE
- $50 / month for unlimited data, talk, and text on our network + up to 3GB of 4G LTE
- $60 / month for unlimited data, talk, and text on our network + up to 5GB of 4G LTE

Plus, get loads of great services like Wi-Fi Calling, in-flight texting, and visual voicemail. And thanks to unlimited data, data overage fees are a thing of the past!

So stop settling and switch to a better prepaid experience.

Learn more

*Rate plan max speed of 8 Mbps; upon reaching data limits, speeds slowed to up to 128 Kbps.

With Smartphone Equality™, another rule bites the dust

We believe everyone deserves a great smartphone. And Smartphone Equality is the proof. It starts with making 12 months of on-time payments and ends with a cool new smartphone for you at our lowest up-front price. And as for credit checks, no need to worry. After 12 months, we have something better than a credit score: history.

Smartphone Equality couldn't be simpler:

1. Make 12 months of on-time payments in a row.
2. Get your next smartphone at our best up-front price like nothing down.

That's it. At T-Mobile, we've already helped you break free from limits, data overages, and annual service contracts. With Smartphone Equality, we're clearing the path to your next new smartphone.

Shop prepaid

*If you finance your device and cancel wireless service, remaining balance on device becomes due. Availability & amount of financing subject to credit approval or consecutive on-time payment history. Must switch to & remain on qualifying service to finance device.

With SCORE!™, why pay full price for your smartphone?

What once was closed to many is now open: killer upgrades to some of the hottest smartphones no matter if you prepaid, brought your last device over to T-Mobile, or bought your phone outright.

For $5 per month, here's the deal:

After 6 months, upgrade at no additional cost to an entry-level 4G smartphone.

OR

After 12 months, get exclusive pricing on our hottest 4G LTE smartphones—like the Samsung Galaxy S5.

At T-Mobile, it's you that matters, not how you pay.

Get started by shopping prepaid phones and adding SCORE! when you activate or by logging in to My T-Mobile and adding SCORE!

Shop prepaid Log into My T-Mobile

*Offers may vary; device availability & pricing subject to change. See list for current sample pricing. For full terms, see www.t-mobile.com/scoreterms.

The Data Strong™ difference

Today's communication is built around data—downloading, streaming, surfing, video chatting, and more. That's why we designed our network differently: for data. With T-Mobile, you'll experience more data capacity per customer than with AT&T and Verizon

Learn more

Devices you'll love at prices you'll love even more

Prepaid customers can now choose from a selection of feature-rich 4G smartphones right for any budget. And with several devices available for under $100, the news couldn't be better.

Shop affordable prepaid phones

The LG L90 shown is $99.84.

Capable device required for LTE speeds. Limited-time offers; subject to change. Taxes and fees additional. **Unlimited talk & text features for direct US communications between 2 people. Simply Prepaid Monthly Service:** Features available until 30th day; if sufficient balance, services automatically renew at expiration. If balance is insufficient to renew for 120 days, account will be suspended for 30 days. If you have a balance, your plan will convert to Pay As You Go for 30-day increments with $3/mo. for 30 voice min./SMS messages. After your balance is depleted, then account is suspended. **Service Changes or Renewals:** When you switch between plan options or renew a monthly plan, features or credits associated with your prior plan option will no longer be available, and you are not able to switch back to some plan options. Some plan options will not allow early renewal. **General Terms:** $15 SIM starter kit may be required. Sufficient balance required to use service. Domestic use only; additional charges apply for international use, where available. Partial megabytes rounded up. Full speeds available up to data allotment, including tethering, with a maximum speed of 8Mbps; then slowed to up to 2G speeds for balance of service period. Certain uses, e.g., some speed test apps, may count against high-speed data allotment or have speeds reduced after allotment reached. Data roaming only available for the $40, $50, and $60 monthly plan options. Roaming and on-network data allotments differ; see your selected service for details. Some plan options do not permit use of features after included amounts are depleted. If you transfer your number to another carrier, account will be deactivated and no service will be available. Devices sold for use on T-Mobile prepaid service are to be activated on that service, not transferred for resale, modification, or export. **SCORE!:** Prices available to current T-Mobile customers enrolled in program. Offers, including device pricing and availability, subject to change. Qualifying plan required; Pay as You Go and Pay by the Day not eligible. See www.t-mobile.com/scoreterms for details. **Smartphone Equality:** Min. 12 mo. on-time or consecutive payments, financed device, and qualifying plan required. **Capacity Claim:** congestion experienced; per customer. **Coverage** not available in some areas. **Network Management:** Service may be **slowed, suspended, terminated, or restricted** for misuse, abnormal use, interference with our network or ability to provide quality service to other users, or significant roaming. LTE is a trademark of ETSI.

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Activate your Prepaid phone or device

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International rates

T-Mobile

Business

Bring your business up to speed with 4G innovations, a powerful network, and flexible plans.

Español

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- PRIVACY POLICY
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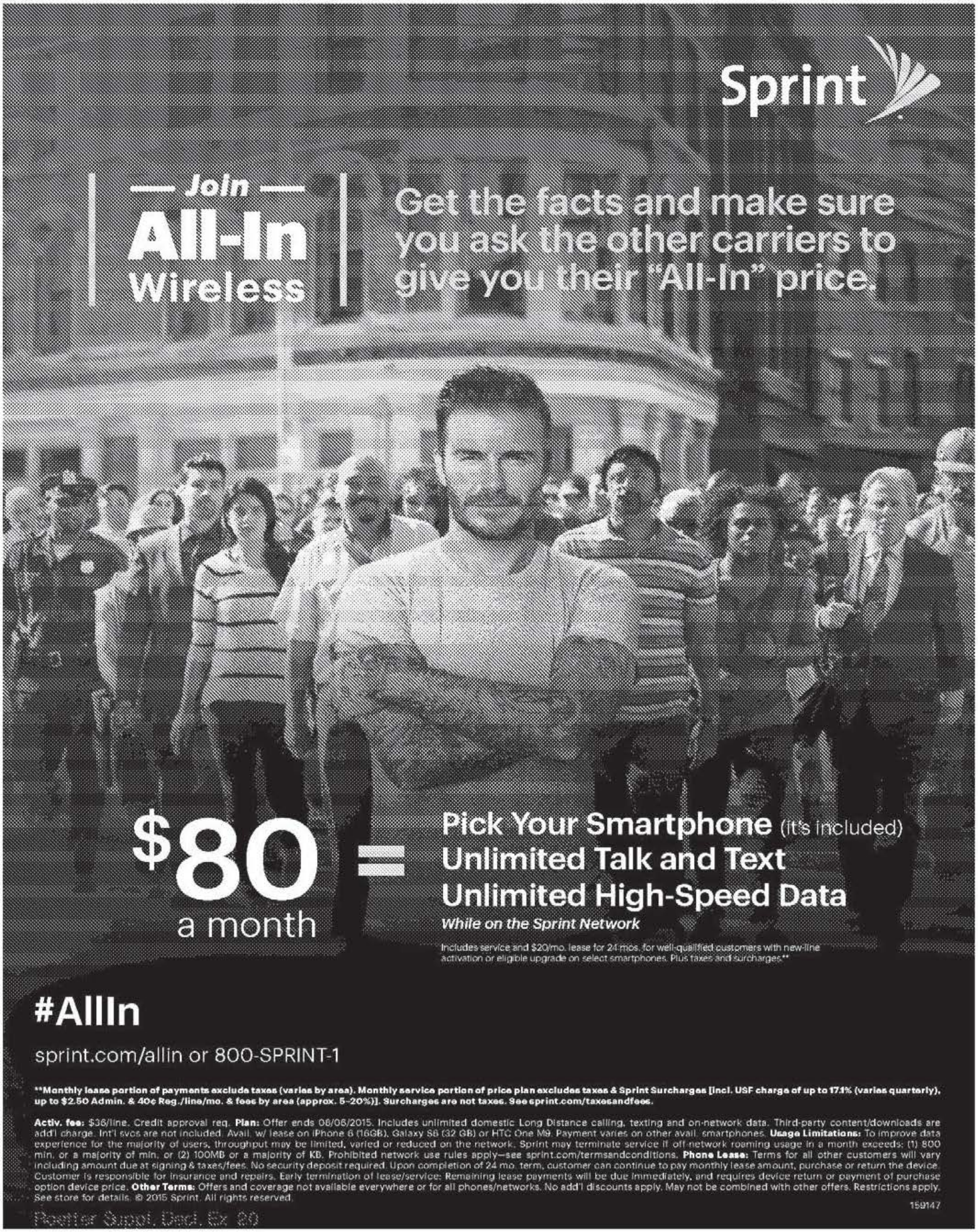
- CONSUMER INFORMATION
- PUBLIC SAFETY/911
- TERMS & CONDITIONS
- TERMS OF USE
- ACCESSIBILITY
- OPEN INTERNET

EXHIBIT SEPARATOR PAGE



Sprint
— Join —
All-In
Wireless
Get the facts and make sure you ask the other carriers to give you their "All-In" price.
$80 a month
=
Pick Your Smartphone (it's included)
Unlimited Talk and Text
Unlimited High-Speed Data
While on the Sprint Network
Includes service and $20/mo. lease for 24 mos. for well-qualified customers with new-line activation or eligible upgrade on select smartphones. Plus taxes and surcharges.**
#AllIn
sprint.com/allin or 800-SPRINT-1
**Monthly lease portion of payments exclude taxes (varies by area). Monthly service portion of price plan excludes taxes & Sprint Surcharges [incl. USF charge of up to 17.1% (varies quarterly), up to $2.50 Admin. & 40¢ Reg./line/mo. & fees by area (approx. 5-20%)]. Surcharges are not taxes. See sprint.com/taxesandfees.
Activ. fee: $36/line. Credit approval req. Plan: Offer ends 06/06/2015. Includes unlimited domestic Long Distance calling, texting and on-network data. Third-party content/downloads are add'l charge. Int'l svcs are not included. Avail. w/ lease on iPhone 6 (16GB), Galaxy S6 (32 GB) or HTC One M9. Payment varies on other avail. smartphones. Usage Limitations: To improve data experience for the majority of users, throughput may be limited, varied or reduced on the network. Sprint may terminate service if off-network roaming usage in a month exceeds: (1) 800 min. or a majority of min. or (2) 100MB or a majority of KB. Prohibited network use rules apply—see sprint.com/termsandconditions. Phone Lease: Terms for all other customers will vary including amount due at signing & taxes/fees. No security deposit required. Upon completion of 24 mo. term, customer can continue to pay monthly lease amount, purchase or return the device. Customer is responsible for insurance and repairs. Early termination of lease/service: Remaining lease payments will be due immediately, and requires device return or payment of purchase option device price. Other Terms: Offers and coverage not available everywhere or for all phones/networks. No add'l discounts apply. May not be combined with other offers. Restrictions apply. See store for details. © 2015 Sprint. All rights reserved.
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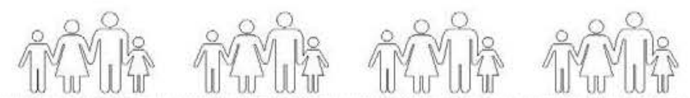
EXHIBIT SEPARATOR PAGE

Sprint

Sprint has the best family plan.

Switch to Sprint and get 4 lines w/ unlimited talk, text and 10GB of high-speed data to share for only $100/mo. after we waive the access charges.

That's more than double the data of T-Mobile. And to get this much data, you'd have to pay $40 more a month at Verizon and $60 more a month at AT&T. All on the Sprint network. Need more data? For just $20/mo. more, you can quadruple your data — that's 40GB to share!



	Sprint	Verizon	AT&T	T-Mobile
Lines	4	4	4	4
High-Speed Data	10GB To Share	10GB	10GB	1GB
Price	$100/mo.	$140/mo.	$160/mo.	$100/mo.
	The Others Don't Compare	Save $480/yr. with Sprint	Save $720/yr. with Sprint	Get more than double the high-speed data with Sprint

T-Mobile's unlimited Simple Choice customers are slowed up to 2G speeds after 2.5GB/line. Comparing to widely advertised family plans: other line/price options available. Competitor plans may include int'l text/data features, data carry over, tethering and cloud options. See carrier websites for details.

Stuck with your carrier? Not anymore.

Sprint will pay off your old phone and contract so you can switch. It's that easy. Via American Express® Reward Card after online registration and current phone turn in.

Switch to Sprint, choose a Sprint Family Share Pack with 10GB or 40GB of data, and acquire your devices with Sprint Easy Pay,℠ leasing option, by paying full MSRP or by bringing your own compatible device. **We will waive the access charges on first 4 lines for as long as you remain on a Sprint Family Share Pack plan with 10GB or 40GB of data.**

Hurry — this is a limited time offer! Go to the nearest store, visit sprint.com/familyshare, or call 800-SPRINT-1.

Switch to Sprint now on Easy Pay or leasing option, and we'll cover your switching fees via American Express® Reward Card.

For up to 4 total devices on Sprint Family Share Pack with 10GB or 40GB shared data/mo. Customers can activate up to 10 lines. Lines 5–10 carry additional data access charges. Requires devices be acquired via Sprint Easy Pay, leasing option, by paying full MSRP or bring your own device. Phones require number switch to Sprint. Tablets/MBBs require new line of service. Requires one active phone line per account.

All pricing and data allowances above are per month.** Requires registration at sprint.com/joinsprint. Restrictions apply. See in-store for more detail.

****Monthly lease payments exclude taxes (varies by area). Monthly charges exclude taxes and Sprint Surcharges [incl. USF charge of up to 17.1% (varies quarterly), up to $2.50 Admin. and 40¢ Reg./line/mo. and fees by area (approx. 5–20%)]. Surcharges are not taxes. See sprint.com/taxesandfees.**

Limited Time Offer. Activ. Fee: $36/line. Credit approval required. Up to 4 lines for just $100/month. **Family Share Pack:** No discounts apply to access charges. Includes unlimited domestic Long Distance calling and texting. Data allowance includes 1GB, 2GB, 4GB, 8GB, 10GB, 40GB or 60GB of shared on-network data usage depending on selection and 100MB off-network data usage. Add'l on-network data usage: 1.5¢/MB. Add'l Off-network data for tablets/MBBs: 25¢/MB. If conflicting share data allowances are applied to an account, the majority on account or most recent change may be applied for all lines. Mobile Hotspot Usage pulls from your data allowances. Third-party content/downloads are add'l charge. Int'l svcs are not included. Max of 10 phone/tablet/MBB lines. Mobile Broadband devices excludes Laptops and notebook computers. **Access Charge Waiver**: Offer is for a limited time. Charges waived for up to 4 total devices. All phone lines must be ported from an active wireless line at another carrier and remain active and in good standing. Devices must be acquired with Sprint Easy Pay, leasing option, by paying full MSRP or by bringing your own compatible device. Excludes 11+ Corporate-liable, upgrades, replacements and ports made between Sprint entities or providers associated with Sprint (i.e., Virgin Mobile USA, Boost Mobile and Assurance). May not be combinable with other offers. High-speed data is 3G/4G. **Usage Limitations:** To improve data experience for the majority of users, throughput may be limited, varied or reduced on the network. Sprint may terminate service if off-network roaming usage in a month exceeds: (1) 800 min. or a majority of min.; or (2) 100MB or a majority of KB. Prohibited network use rules apply—see sprint.com/termsandconditions. **Sprint Easy Pay:** Req. 24-mo. installment agreement, 0% APR, and qualifying device and service plan. **If you cancel wireless service, remaining balance on device becomes due. Phone Lease Agreement:** Credit approval req. Terms for all other customers will vary including amount due at signing & taxes/fees. Req. qualifying device & service plan. No equipment security deposit required. Upon completion of lease term, customer can continue to pay monthly lease amount, purchase or return the device. Customer is responsible for insurance and repairs. **Early termination of lease/service:** Remaining lease payments will be due immediately, and requires device return or payment of purchase option device price in lease. **Contract Buy Out Offer:** Consumer, SDP and CL lines purchasing a new device with: Sprint Easy Pay, Sprint Lease, iPhone for Life Plan, at full MSRP, or Certified Pre-Owned and porting the new line on a service plan. Amount based on ETF (early termination fee) charged or remaining balance on install-bill device (excludes prepaid devices). All lines must be ported from an active wireless line at another carrier and remain active and in good standing to receive the American Express Reward Card. Requires you turn in your current competitor phone associated with the installment billing balance or ETF submitted to Sprint. Important: If you do not turn in the correct device in good working order (i.e. the phone powers on, the screen is intact, and there are no broken, missing, or cracked pieces. Apple phones must have the activation lock disabled), you will be charged up to the amount of the Reward Card provided to you. You must register and submit your final bill showing your ETF or installment balance within 60 days of switching to Sprint. Allow approximately 15 days for your Reward Card to arrive after your registration has been approved. Register at sprint.com/joinsprint. Excludes 100+ Corporate-liable, upgrades, replacements and ports made between Sprint entities or providers associated with Sprint (i.e., Virgin Mobile USA, Boost Mobile, and Assurance). **Reward Card:** Terms and conditions apply to Reward Cards. See Cardholder Agreement or visit www.americanexpress.com/sprint for details. Subject to applicable law, a $3.00 monthly service fee applies beginning in the seventh month after Card issuance. Card is issued by American Express Prepaid Card Management Corporation. American Express is not the sponsor of this promotion. **Other Terms:** Offers and coverage not available everywhere or for all phones/networks. See sprint.com/coverage for details. May not be combined with other offers. There is no minimum term applied on the Sprint Family Share Pack, but the Service Agreement applies and automatically continues on a month-to-month basis unless you contact us to inform us of any changes, including cancellation. There may be a minimum annual term applied or continued based on a discounted device purchase. Restrictions apply. See store or sprint.com for details. Sprint and the Sprint logo are trademarks of Sprint. Other marks are the property of their respective owners.

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White paper

Mobile broadband with HSPA and LTE – capacity and cost aspects

Nokia Siemens Networks

Contents

The latest generation of smart devices and USB data modems for mobile computers has created explosive growth in network data traffic. In particular, mobile broadband via High Speed Packet Access (HSPA) has led to a significant rise in the number of subscribers and the amount of data they use. The volume of data traffic carried by cellular networks has already exceeded that of voice traffic.

However, managing the ongoing growth of data traffic is a significant challenge for communications service providers (CSPs) who need to undertake careful planning of the network structure to achieve the performance that data services demand.

This paper analyzes the maximum radio capacity of mobile broadband solutions from the viewpoint of traffic quality vs. traffic distribution over time and location. It suggests that user data rates can be improved by adding macro sites in hot spots, deploying six sector sites and implementing quality of service differentiation.

Secondly, the paper gives a high level view of the cost of mobile broadband services, taking into consideration the volume of data traffic per user and the number of active data subscribers per site. The key finding is that monthly network Capital Expenditure (CAPEX) and Operational Expenditure (OPEX) can be kept below 3 EUR per subscriber over an eight-year depreciation period. This is true if the average mobile broadband penetration is at least 500 subscribers per site, and if subscribers use less than 2 GB per month.

Radio capacity of mobile broadband

This section uses typical traffic distribution assumptions from live networks to estimate the maximum network capacity with HSPA and Long Term Evolution (LTE). The intention is to derive an approximate value for the maximum number of subscribers that can be supported by a specific base station site density with given spectrum resources. Figure 1 illustrates the estimation process.

High Speed Downlink Packet Access (HSDPA) terminals send a Channel Quality Indication (CQI) to the base station every few milliseconds when they are sending or receiving data. The CQI indicates the maximum possible data rate that the terminal can receive with an error rate of less than 10%. CQI reports are used mainly for link adaptation and for packet scheduling algorithms, but they can also be used to estimate the maximum air interface capacity for network dimensioning.

Figure 2 shows an example CQI distribution over the whole network. For reference, CQI 15 corresponds to approximately 2.2 Mbps, CQI 20 to 4.9 Mbps and CQI 25 to 8.3 Mbps of HSDPA throughput. These throughputs assume that the cell is carrying only HSDPA traffic and no WCDMA Release 99 traffic. The median CQI value in Figure 2 is 21, which corresponds to 5.7 Mbps throughput.

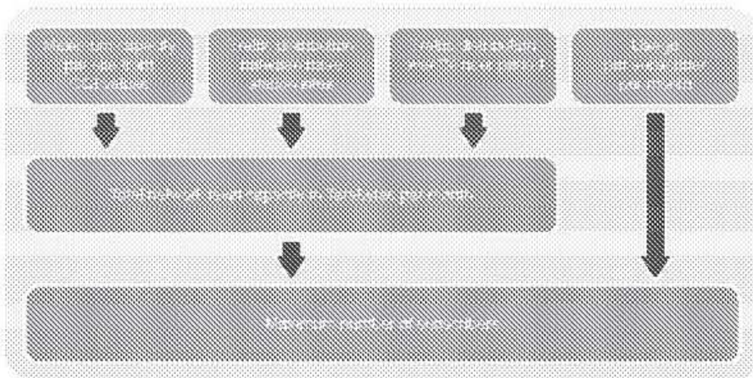

Figure 1. Estimation of the maximum number of supported subscribers in the network

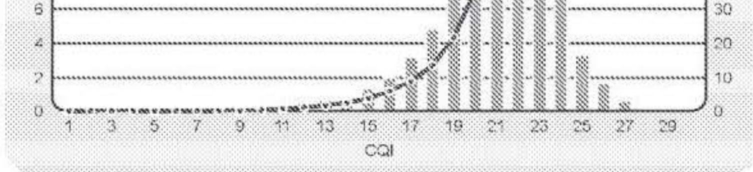

Figure 2. Example CQI distribution

System level packet scheduling gains can increase cell throughput slightly, so in this example we assume 6 Mbps average cell throughput, which means 6 Mbps per 5 MHz carrier per sector in HSPA. The CQI values are affected by network planning, by the level of other-cell interference and by the performance of the terminal receivers. For LTE, we assume 35 Mbps cell throughput for 20 MHz bandwidth, which corresponds to 50% higher spectral efficiency than with HSPA.

A margin in network dimensioning in the busy hour needs to be reserved in order to guarantee low delays and reasonably good data rates. In this example, a maximum 50% loading of the CQI values over the busy hour is assumed, which leads to an average busy hour throughput of 6 Mbps x 50% = 3 Mbps per cell in HSPA and 17.5 Mbps per cell in LTE 20 MHz. The 50% margin is not constant but depends on the targeted user data rates and on the applications. If background download applications are mainly being used, the busy hour loading could be more than 3 Mbps.

Traffic is never equally distributed between sites. In a network, several sites will provide coverage, but will not be fully loaded. Figure 3 illustrates an example traffic distribution during the busy hour in which 50% of the traffic is carried by 15% of the cells. In estimating the maximum network capacity, this paper always assumes that it is those 15% of the cells that become congested and limit the total capacity. At the same time, 85% of cells are not congested.

Network capacity could be improved by adding cell sites to the congested areas. The traffic distribution depends on the network deployment, country geography and number of users. **Typically, more users lead to a more equal traffic distribution between sites.**

Traffic is also not equally distributed over a 24 hour period. The busy hour in data networks is typically in the evening, but data traffic is also generated during the night. Figure 4 shows an example traffic distribution in which the busy hour carries 7% of the network's daily traffic.

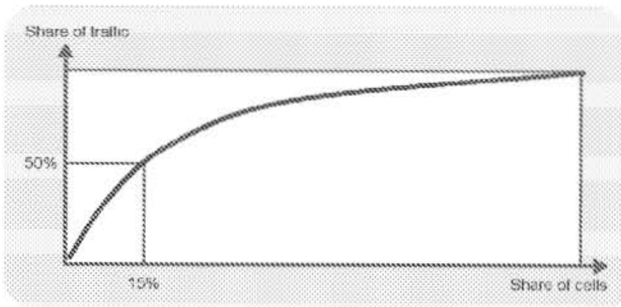

Figure 3. Example traffic distribution between cells

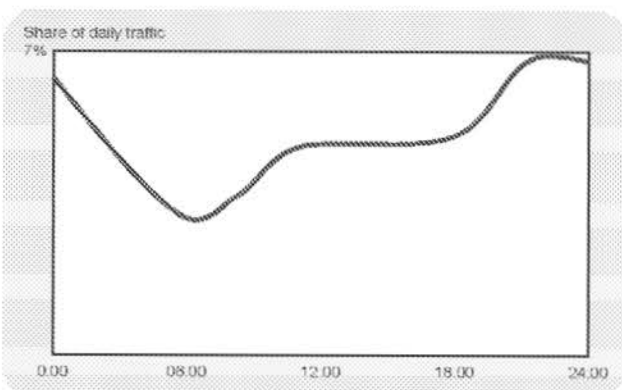

Figure 4. Example traffic distribution over a 24-hour period

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Figure 5 shows typical European spectrum resources. HSPA is deployed at 2100 and 900 while LTE is used at 2600, 1800 and 800. The total amount of spectrum is assumed to be 2 x 70 MHz paired spectrum per CSP.

Now, let's make an example capacity calculation with 10,000 and 20,000 base station sites, each with three sectors. Such a network would be typical of a large European country. It is assumed that each subscriber consumes an average of 5 GB of data per month in the downlink and uplink together, which is more than a typical user on an HSPA network today.

The capacity is assumed to be downlink limited, while uplink use is assumed to be 30% of downlink use. This corresponds to 3.8 GB of downlink data and 1.2 GB of uplink data. For reference, typical voice use is 300 minutes per month, which corresponds to 36 MB of data in the downlink with 16 kbps equivalent data rate. Therefore, voice will be a minor part (1%) of the total traffic, but voice requires strict Quality of Service assurance to provide low delay and low error rate.

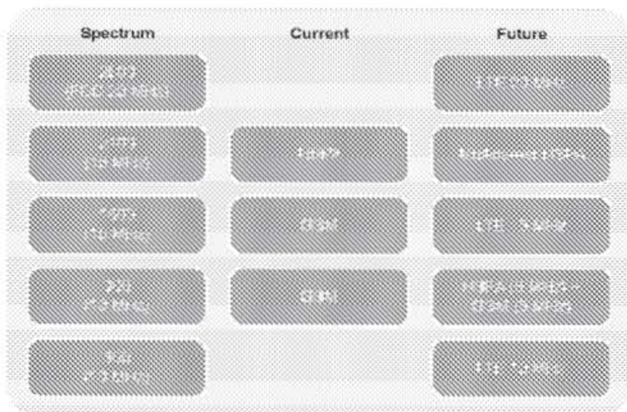

Figure 5. Assumed spectrum resources

The maximum number of subscribers is estimated by the following equation:

$$\text{Subs} = \frac{\text{Cell\_capa[Mbps]}}{\text{8192Mbit/GB} \cdot \text{3.8GB/sub}} \cdot \text{3(sectors)} \cdot \text{3600s/hour} \cdot \text{30days/month} \, \frac{\text{50\%(maxload)}}{\text{7\%(busy hour share)}} \cdot \text{Sites} \cdot \frac{15\%}{50\%} \text{(distribution)}$$

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Figure 6 shows the results. With 10,000 sites, the radio network can support up to 5 million data subscribers with HSPA and up to 22 million data subscribers with HSPA and LTE. With 20,000 sites, the capacities would be 10 million HSPA subscribers and 45 million with HSPA and LTE. Typically, existing networks with 10,000 sites have of the order of 20 million voice subscribers, while networks with 20,000 sites have 40 million subscribers. These calculations indicate that HSPA and LTE radio networks with typical spectrum allocation can provide 5 GB of data for all existing voice subscribers.

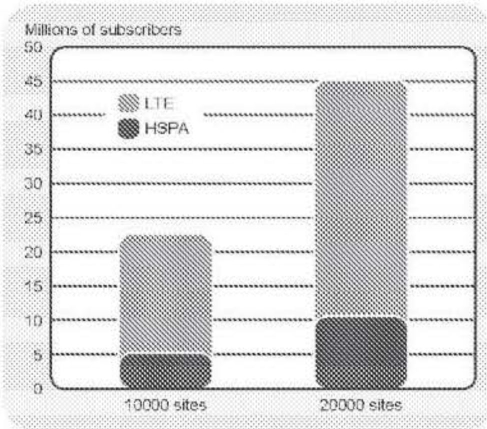

Figure 6. Maximum number of broadband subscribers, each consuming 5 GB/month (using spectrum allocation from Figure 5)

Another way to calculate capacity is to consider user data rates. Let's aim for a minimum of 1 Mbps user data rate. A so-called overbooking factor can be used to take into account the fact that only a small proportion of users will typically be downloading data at the same time. 3.8 GB of downlink data per month with 7% busy hour share corresponds to 20 kbps average data rate per subscriber during the busy hour, which is equal to an overbooking factor of 1 Mbps/20 kbps = 50.

User expectations for data rates depend on the market, as well as the application and terminal being used. Markets with high wireline broadband penetration tend to have higher expectations for mobile broadband data rates, while users in markets with poor wireline broadband availability may be happy with lower data rates. Therefore, the dimensioning rules need to be adapted to market conditions.

The following solutions can be used to provide even more capacity and to support more subscribers:

- More macro sites could be added to congested areas. Nokia Siemens Networks Flexi base stations are compact, have zero-footprint and are fully deployable outdoors, which can make site acquisition simpler compared to conventional base station designs.
- 6-sector sites offer typically 40–50% more capacity per site compared to 3-sector sites and up to 80% in the best case. (Source: "All-in-one mobile site solution boosts 2G, 3G and LTE network coverage and capacity", Nokia Siemens Networks press release, November 4, 2009).
- QoS differentiation can be applied to control the priority of heavy users when they exceed their monthly quota. Typically, a small percentage (less than 20%) of users takes most of the capacity (more than 80%).
- Offloading traffic from the macro network to small cells like micro or femtocells (home NodeB/eNodeB). 3GPP Releases 8 and 9 include a number of enhancements for femtocells, including optimized architecture, as well as two-way handovers between macro and femtocells. 3GPP Release 10 includes the work item "Heterogeneous networks", that provides enhanced interworking between macro cells and small cells.

The cost of mobile broadband capacity

This section estimates the cost of mobile broadband capacity and uses the following assumptions:

- HSPA and LTE radios are considered with minimum configuration of HSPA 1+1+1 (5 MHz) and maximum configuration of HSPA 4+4+4 @ 900 (5 MHz) and 2100 (15 MHz), and LTE 3+3+3 @ 800 (10 MHz), 1800 (15 MHz) and 2600 (20 MHz).
- The network CAPEX ranges from 40,000 to 400,000 EUR per site depending on the configuration. The minimum CAPEX corresponds to HSPA 1+1+1 configuration, while the maximum CAPEX corresponds to HSPA 4+4+4 and LTE 3+3+3 configurations. The CAPEX per site is assumed to be linear with the site capacity.
- CAPEX depreciation occurs over 8 years.
- The annual OPEX ranges from 8,000 to 80,000 EUR per site, depending on the configuration, including backhaul, site rental, power consumption and radio network software and hardware maintenance. The OPEX is clearly higher than CAPEX depreciation, and therefore, it is essential to minimize network OPEX.
- We assume that 100% of OPEX is allocated for data but, in practice, part of the OPEX could also be allocated to voice traffic because the base station sites also provide the voice network. This would make the data cost lower than that shown in the calculations in this paper.
- Site configuration is selected according to traffic requirements. Here, the same traffic distribution as in capacity calculations is assumed, in which 15% of the cells carry 50% of the traffic.

Figure 7 shows the cost per subscriber as a function of subscriber density per base station site. Figure 8 shows cost per gigabyte as a function of mobile broadband penetration.

Subscriber density is the average value over the whole network. If the average number is, for example, 500 subscribers per site, there will be sites in the network supporting 1,000–2,000 subscribers, while many sites will provide mainly coverage for a few subscribers. Figure 8 assumes that there are, on average, 2,000 voice subscribers per site.

The CAPEX + OPEX per subscriber are relatively high when the subscriber density is low. The cost reduces when there are more subscribers sharing the costs. With at least 500 subscribers per site each using less than 2 GB/month, the monthly CAPEX + OPEX will be below 3 EUR per subscriber. If the average data usage can be kept less than 2 GB and the subscriber density is very high, it is possible to push the monthly CAPEX + OPEX below 2 EUR. If the site rental and backhaul costs are partly allocated to voice, then the monthly CAPEX + OPEX for broadband data will be even lower.

The cost of delivering a GB of data is highly dependent on the network utilization. If total data use is high, either due to a high number of subscribers or to high use per subscriber, the cost per GB can be below 1 EUR. Figure 8 shows that a cost of less than 1 EUR can be obtained with 40% mobile broadband penetration and 2 GB/sub/month.

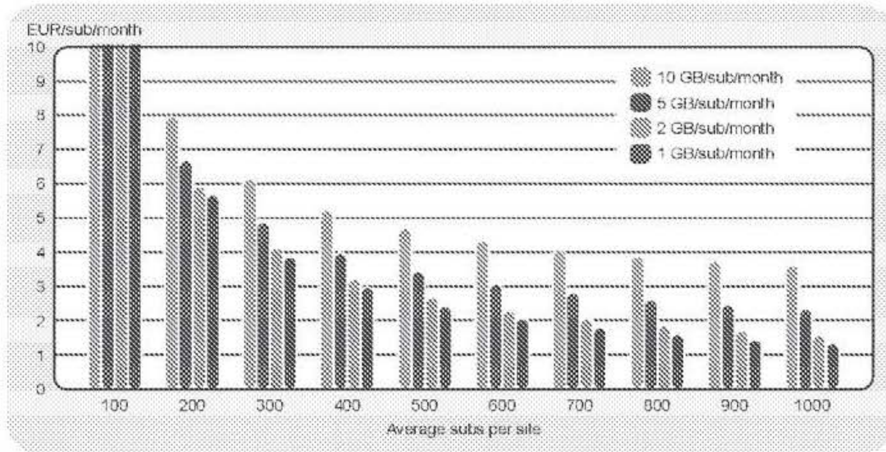

Figure 7. Network CAPEX + OPEX per sub per month

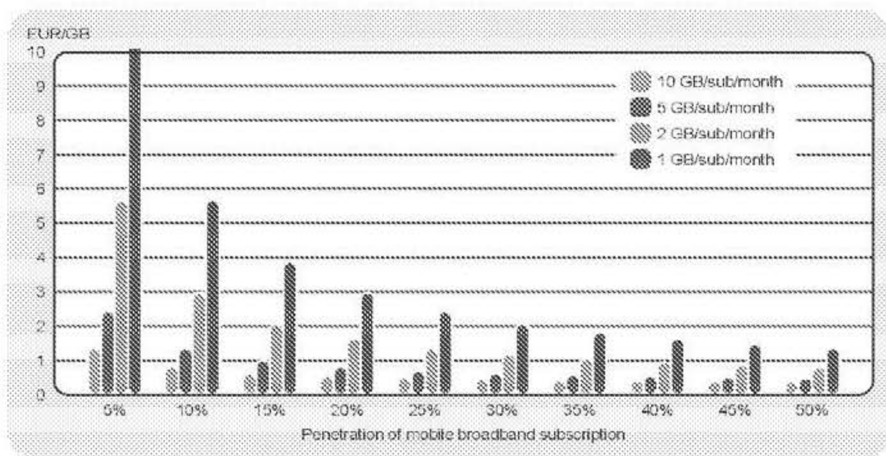

Figure 8. Network CAPEX + OPEX per gigabyte of data

A few notes on the cost calculations:

- The most important factor in the cost calculations is network OPEX because it is typically higher than CAPEX. The largest contributors to OPEX are backhaul transport, site rental, network maintenance and electricity. Other OPEX factors, like customer acquisition and marketing, are not considered here.
- It is essential to minimize OPEX by using efficient Ethernet transport, for example Ethernet based microwave radio, fiber or DSL, and by re-using existing base station sites.
- The mobile broadband cost depends on how the site and transport costs are shared between voice and broadband data.
- The relationship between cost and traffic per subscriber is not linear. If the traffic per subscriber grows ten-fold, the cost will increase only two- to three-fold. This is because the radio networks must always provide basic coverage even in low traffic areas. When the traffic increases, the low traffic areas do not need capacity upgrades. Furthermore, many cost elements in the high traffic areas remain similar or grow only moderately with traffic volumes. Such costs include site rental and backhauling costs. In other words, high data penetration and high data usage leads to lower cost per GB. Therefore, CSPs with a large market share will benefit from economies of scale.
- LTE with new spectrum allocations is efficient for carrying higher traffic volumes. The benefit of LTE becomes clear when HSPA spectrum has already been fully utilized and further HSPA capacity would require new and costly base station sites.
- Sufficiently high LTE terminal penetration is needed to offload traffic from HSPA to LTE. If LTE terminal penetration is low, it may be more cost effective to upgrade the capacity of the existing HSPA network than to deploy an LTE network.
- Small femtocells can provide a significant capacity offload from the macro network, if marketed to users with appropriate use patterns. Macro cell traffic can also be offloaded to WLAN (WiFi) networks.

Summary

The advent of smart devices and mobile computers has generated explosive growth of data traffic that challenges CSPs to make well-timed and focused investments. This paper shows that, with typical European spectrum resources, it is possible to provide up to 5 GB of data per month for every existing voice subscriber by using HSPA and LTE radios in existing sites. Radio capacity can be boosted further by deploying additional macrosites in hot spots, using 6-sector configurations, applying QoS differentiation, and by using micro- and femtocells in highly populated areas.

It is possible to provide up to 5 GB of data per month for every existing voice subscriber by using HSPA and LTE radios in existing sites.

Monthly network CAPEX + OPEX can be kept below 3 EUR per subscriber over an eight-year depreciation period if average mobile broadband penetration is at least 500 subscribers per site, and if data use is below 2 GB per subscriber per month. 500 subscribers correspond typically to 25% mobile broadband penetration. It is essential to re-use existing base station sites, and to deploy efficient Ethernet transport solutions using microwave radio or fiber.

The cost of delivering a gigabyte of data per subscriber can be less than 1 EUR if total data use is high enough. LTE networks can lower the cost per bit, especially when HSPA spectrum is fully utilized, because adding LTE capability to existing sites costs much less than adding new HSPA sites. However, for this to be viable, sufficient LTE terminal penetration is needed to drive traffic onto the LTE network.

This study provides an essential lesson: Increasing the subscriber base is vital for CSPs to achieve lower data delivery costs. This is because radio networks benefit from significant economies of scale, with high data penetration and high data use leading to lower cost per GB.

The continued growth in smart device and mobile computer data traffic is creating a major disruption in the telecommunications industry that will require CSPs to accurately plan the timing and focus of their network investments.

Monthly network CAPEX + OPEX can be kept below 3 EUR per subscriber over an eight-year depreciation period if average mobile broadband penetration is at least 500 subscribers per site, and if data use is below 2 GB per subscriber per month.

Abbreviations

3GPP	Third Generation Partnership Project
CAPEX	Capital Expenditure
CQI	Channel Quality Indication
CSP	Communications Service Provider
DSL	Digital Subscriber Line
CQI	Channel Quality Information
GB	Gigabyte
HSDPA	High Speed Downlink Packet Access
HSPA	High Speed Packet Access
LTE	Long Term Evolution
OPEX	Operational Expenditure
QoS	Quality of Service
WCDMA	Wideband Code Division Multiple Access
WLAN	Wireless Local Area Network

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Exhibit X: US Cellular Data Usage

FierceWireless

Published on FierceWireless (http://www.fiercewireless.com)

Report: U.S. consumers swallowed 2.5 GB/month of cellular data in Q1 on average

May 19, 2015 | By Phil Goldstein

U.S. consumers on average chewed through around 2.5 GB of cellular data per month in the first quarter, according to industry analyst Chetan Sharma, up from an average of 2 GB per month at the end of 2014.

"In the U.S., it took roughly 20 years to reach the 1 GB/user/month mark," Sharma wrote in a research report. "However, the second GB mark has been reached in less than four quarters. An entire year's worth of mobile data traffic in 2007 is now reached in less than 75 hours."

Sharma's figures are roughly in line with those from Cisco Systems. In its latest Visual Networking Index Global Mobile Data Traffic Forecast report, which was released in February, Cisco found that in 2014, consumers in North America used on average 1.89 GB of mobile data per month in 2014. Cisco thinks that figure will surge ahead to a little more than 11 GB on average in 2019.

According to Sharma, data made up 62 percent of all wireless carrier service revenues in the U.S. in the first quarter, up from 60 percent in the fourth quarter of 2014 and around 50 percent in the year-ago period.

Data usage is clearly increasing, both in the U.S. and other markets around the world, but more and more consumers are likely going to be offloading that traffic to Wi-Fi networks, according to a new report from Juniper Research.

The research firm reported that mobile data traffic will reach nearly 197,000 petabytes by 2019, equivalent to over 10 billion Blu-ray movies. However, the research firm found that only 41 percent of the data generated by smartphones, tablets and feature phones will be carried over cellular networks by 2019, with the majority of mobile data traffic offloaded to Wi-Fi networks.

"Certainly, video is forming an ever-greater proportion of network traffic. For example, Juniper Research anticipates that video traffic over smartphones will increase by nearly 8 times between 2014 and 2019", Juniper Research analyst Nitin Bhas said in a statement.

Video currently accounts for around 60 percent of global IP traffic and, in some developed markets, this proportion is likely to exceed 70 percent in two to three years. In 2014, data traffic generated by smartphones, feature phones and tablets in the Far East and China exceeded that of North America for the first time, Juniper reported.

For more:- see this Chetan Sharma report- see this Juniper Research releaseRelated Articles:Verizon criticized for posting blog that suggests customers do not want or need unlimited dataPew: 64% of American adults have a smartphone, and 10% rely on it for their broadband connectionReport: LTE drives up mobile data consumptionEricsson: Facebook, YouTube, Netflix, Instagram and Snapchat make up 61% of U.S. mobile app trafficCisco: N. American mobile users to each consume around 11 GB per month by 2019

Source URL: http://www.fiercewireless.com/story/report-us-consumers-swallowed-25-gbmonth-cellular-data-q1-average/2015-05-19

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Nokia Networks

Deployment Strategies for Heterogeneous Networks

White Paper

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Executive Summary

The growing demand for affordable mobile broadband connectivity is driving the development of Heterogeneous Networks (HetNets). A range of different Radio Access Technologies (RATs from 3GPP and IEEE such as Wi-Fi) will all co-exist, and macro cells will be complemented by a multitude of smaller cells, such as micro/pico BTS (base stations), low power remote radio heads (RRH) and femto cells. Such heterogeneous systems will be significantly more complex to deploy than today's networks and will therefore require simple and robust deployment strategies.

- The first step is to ensure mobile broadband (MBB) coverage, which involves extending existing macro base stations, for example, using lower frequency bands such as UMTS850/900 and LTE700/800 as well as deploying small cells in key indoor locations or for in-fill.
- The next step is to increase capacity using additional spectrum (such as 2600 MHz or refarming of 1800/1900 MHz), applying higher sectorization and adding more macro base stations. This, combined with site renewal, for example, by upgrading with Radio Antenna System (RAS) or Active Antenna Systems (AAS), will minimize additional site acquisition/upgrade costs.
- Once all these measures have been exhausted, operators should deploy outdoor and indoor base stations to create smaller cells in congested network areas, for example hot zones. They need to ensure that this network densification is well managed and integrated with the existing Single Radio Access Network (RAN). Feature parity of small cells with the macro cells is key to enabling a seamless user experience. Before adding capacity, some operators will deploy small cells in strategic outdoor and public indoor locations to improve the subscriber experience in key areas such as business districts and conference centers.

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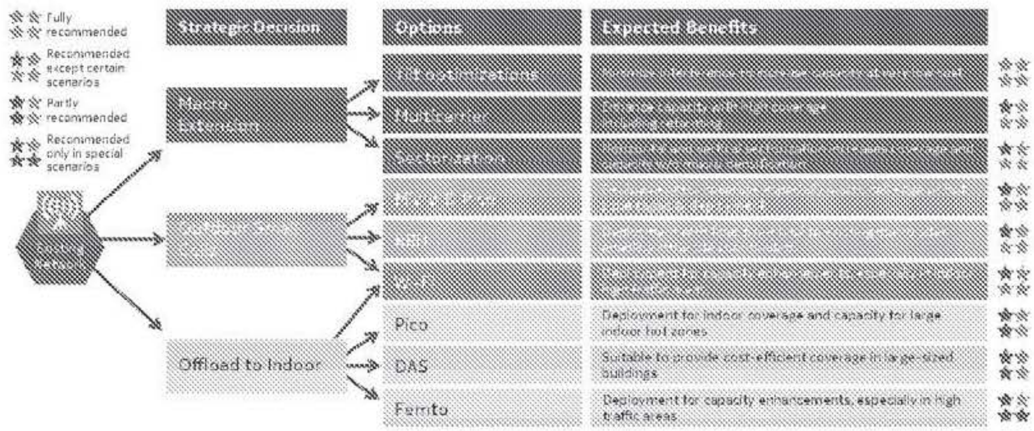

Figure 1. Deployment options for Heterogeneous Networks

This whitepaper outlines key deployment strategies for HetNets and explains how Nokia Networks can help operators address them. It discusses how to design roadmaps to expand the macro layer and how to use outdoor and indoor small cell layers to handle increasing traffic.

Multiple Deployment Options for Operators

Cellular data traffic has taken off rapidly since High Speed Packet Access (HSPA) was launched, driven by the increasing penetration of smartphones and tablets. Data traffic is expected to continue to grow significantly over the coming years.

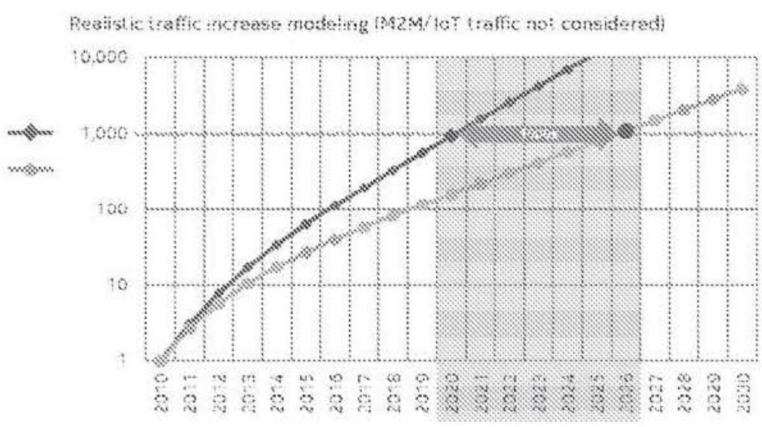

Figure 2. Expected Mobile Broadband traffic growth

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The Nokia Networks traffic model is based on the following three simple assumptions:

- Mobile broadband penetration reaches 100% in 2020 (15% in 2010)
- Traffic volume per subscriber increases annually between 25% & 50%
- Total subscriber base increases annually by 10%

This results in a traffic increase (relative to 2010) of 1000x between 2020 and 2026. A simple and well known deployment strategy will be vital if operators are to plan and install a network that can cope with this significant traffic increase.

Operators can choose from a wide range of deployment options, beginning with full utilization of the existing macro layer and deployment of Long Term Evolution (LTE). Small cells will be required to add extra capacity to deal with increased growth. In the meantime, MNO need to continuously seek to acquire more spectrum & utilized unlicensed spectrum when required.

Key focus on Macro layer utilization

Many operators already have wide-area Global System for Mobile (GSM) coverage and HSPA in densely populated urban areas. Many operators have also deployed LTE in dense urban areas and some have deployed LTE in rural areas to exploit the digital dividend, as is the case in Germany.

One of the key elements to cope with increasing traffic is the higher spectral efficiency provided by LTE compared to HSPA and GSM. Therefore, the first step is to deploy LTE where possible, using the LTE handset penetration in the subscriber base. As of 2014 there are 497 million LTE subscribers, and LTE has a global penetration of approximately 7%. LTE and LTE-Advanced are growing rapidly throughout the world with an annual growth of 141%. Operators with high LTE handset penetration can better exploit the LTE layer and spectrum. [Source 4GAmericas]

Many operators are re-farming existing GSM frequency bands to HSPA or LTE, so they can update their equipment gradually to more spectrally efficient radio standards. Some operators are even re-farming HSPA for LTE. GSM, HSPA and LTE will continue to coexist and evolve in the long term for several reasons:

- GSM may be the only system providing ubiquitous voice coverage and is being used by a large population of legacy terminal users, for example, pre-paid customers, roamers from foreign countries, or machine-to-machine (M2M) applications such as smart metering.
- Low cost smartphones mainly rely on HSPA as the underlying MBB technology.
- LTE penetration is well established and many of the best-selling handsets support LTE [http://www.gsacom.com/news/statistics].
- LTE handset penetration differs from region to region from <1% to 47% with a global average of 1.7% [Source 4GAmericas]

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Macro Cell splitting and Sectorization

Macro cells carry most of the traffic in today's mobile network, supplemented by small cells in hot zones. One of the key performance multipliers for macro cells is to subdivide each cell into smaller cells, boosting the site capacity significantly. There are basically two ways to split a macro cell; in the horizontal or azimuth domain and in the vertical domain. Combining both horizontal and vertical sectorization provides a narrow beam targeting only a single or a few users. This can be done by deploying active antenna systems and has been standardized in 3GPP Release 12.

The role of new spectrum

New bands are under consideration for the further deployment of macro and small cells. Firstly, operators need to make full use of their existing spectrum and refarm legacy spectrum that is not being fully used to HSPA and LTE. Once full use is being made of the existing spectrum, new spectrum opportunities need to be evaluated, such as 3.4-3.6 GHz. Furthermore, World Radio Conference 2015 will explore new spectrum in the 700, 1400, and 2700 MHz bands. The lower spectrum is ideal for macro coverage in both rural and urban areas, while the upper frequencies can be used as dedicated small cell spectrum or even as a macro deployment in dense urban areas.

The evolving roles of small cells

In the early days of GSM and until recently with HSPA, small cells were mainly used for fill-in purposes. This practice will continue, with small cells being used for cases where macro cells are difficult to deploy, such as in protected buildings and for public indoor sites. Small cells will play a key role in operators' future networks and the large majority of small cell deployments will support the macro layer to add capacity or boost end user performance when and where required.

The cellular standards already mentioned will continue to exist alongside local area wireless technologies such as Wi-Fi. Wi-Fi is becoming ever more tightly integrated with 3GPP networks via the 3GPP standards effort and vendor innovation, such that Wi-Fi is now considered a fourth RAT for HetNets. Adding capacity to a cellular network via Wi-Fi is highly cost-effective for operators, allowing them to reduce traffic in their HSPA and LTE networks and use comparatively inexpensive backhaul infrastructure. In fact, Wi-Fi is already ubiquitous in almost all homes and offices. A mobile operator that also owns the Wi-Fi access infrastructure in public indoor locations or outdoor, can deliver a seamless data experience for end users. In addition, pretty much all smartphones sold today have Wi-Fi capabilities.

Many networks will include an overlay of cells of different sizes. For instance, outdoor users may be served by a combination of macro, micro and pico cells. Low power RRH and pico cells may provide both

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outdoor and indoor coverage/capacity in hotspots/hot zones such as shopping districts, train stations or shopping malls, with a typical cell radius of up to 200 meters. Indoor pico and femto cells are used indoors in cells of no more than 10-25m radius. While pico cells are deployed by an operator, femto cells are typically user-deployed. The trend towards multi-layer deployments, or small cell densification, is driven by the need to provide better service quality both indoors and outdoors. The small cells should have the same features as the macro cells to give a seamless user experience when moving between the two.

In most 3G and LTE networks today, operators are also seeing some areas of their networks with a much more rapidly growing capacity demand than in others. These former hotspots have effectively evolved into much larger hot zones, outdoor and indoor areas that cannot be covered by a single or a few micro/pico cells. Small cells have a key role to play in supporting capacity and better subscriber performance in these hot zones. However, the nature of such dense small cell deployments and i the resulting high number of new small cells in operators' networks are bringing their own set of new challenges and a need to reexamine the total cost of ownership of this small cell underlay.

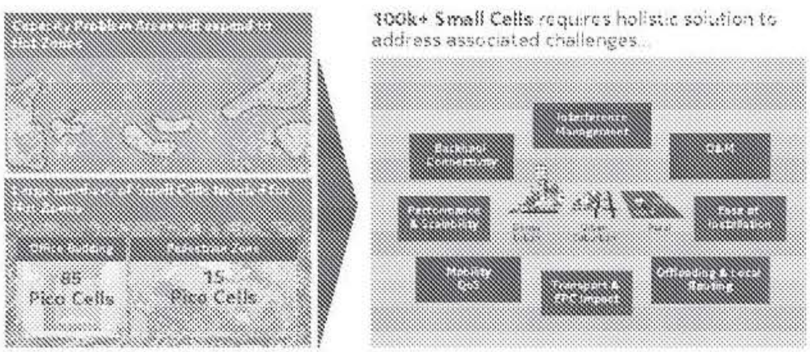

Figure 3. Hot zones define the needs for different and more holistic small cell capacity solutions

An optimal network expansion roadmap depends on various operator location-specific parameters and assumptions, such as:

- The legacy infrastructure in terms of sites, base stations and transport.
- Availability of new sites.
- Type of sites available.
- Health regulations governing authorized emitted RF power
- The availability of spectrum and terminals for specific RATs.
- Traffic demand, user mobility and revenue forecasts for a particular area and the area parameters.

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- Cost-related aspects (such as backhaul infrastructure, site rental, labor and energy).
- General strategic decisions regarding services to be provided and the metric to be optimized (such as ubiquitous connectivity anytime and for anybody versus peak data rates for certain consumers).

Establishing an expansion roadmap requires a way to assess the overall performance, detailed cost models and adequate measurement data. The effect of the uncertainty in parameters such as traffic forecasts can be mitigated by investing in flexible base stations, where changes can be made later via a software upgrade.

Macro Layer Evolution

The number of RATs and frequency variants increases the complexity of mobile networks. Operators will typically have three RATs (GSM/CDMA, HSPA and LTE) and up to six frequency variants running in parallel, as illustrated in Figure 4.

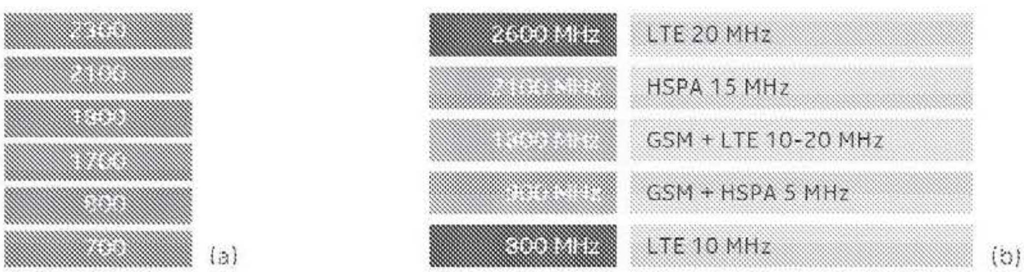

Figure 4. Typical future single RAN configuration in the US (a), and in Europe (b).

At the same time, network operation must be simplified and the base station site solution must be compact. These requirements can all be tackled with single Radio Access Network (RAN) base stations. Single RAN brings benefits in terms of common antennas and backhaul transmission between multiple RATs. Single RAN Advanced from Nokia Networks provides the most compact macro site solution, with future-proof evolution achieved through software upgrades.

A multi-carrier upgrade is a simple and cost-efficient method for upgrading the macro network where spectrum is available. Refarming part of the 2G spectrum, such as 850/900MHz and 700/800 to HSPA enables better MBB coverage, especially indoors. It also allows micro cells to be deployed on the existing 3G spectrum, such as 2100 MHz.

New LTE bands such as 700, 800, Advanced Wireless Services (AWS) and 2600 MHz are available, including refarming the 1800/1900 MHz band from GSM to LTE. Many networks were designed for voice

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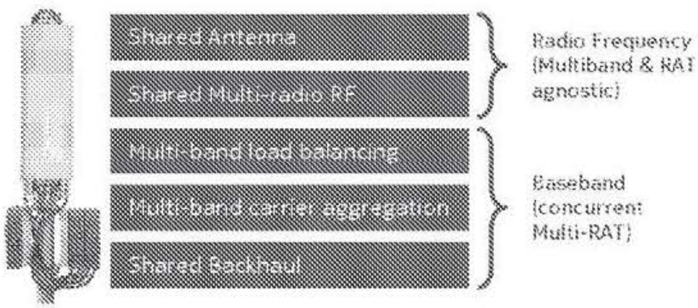

Figure 5. Nokia Networks Single RAN Advanced for the macro cell network

coverage and with the increase in data rates, the coverage area may shrink owing to power limitations in user devices. Therefore, macro site upgrades may require additional densification, increased base station output power or further cell-splitting or sectorization.

Antenna tilt optimization is a cost-efficient way to increase the signal-to-interference noise ratio (SINR) in the macro network. Typical initial deployments were focused on coverage and now that capacity is the limiting factor, the antenna tilt can be optimized in many networks. Our studies have shown that a full-scale network antenna tilt optimization can gain up to ~2dB compared to the deployed network. The tilt settings can be tuned either by mechanical tilt (on-site modifications) or by electrical tilt (remote modifications), which will be used by self-optimization functions.

Higher order sectorization can be deployed in both the horizontal plane by increasing the number of antennas/sectors and in the vertical plane by introducing Active Antenna System (AAS). An example of sectorization is shown in Figure 6.

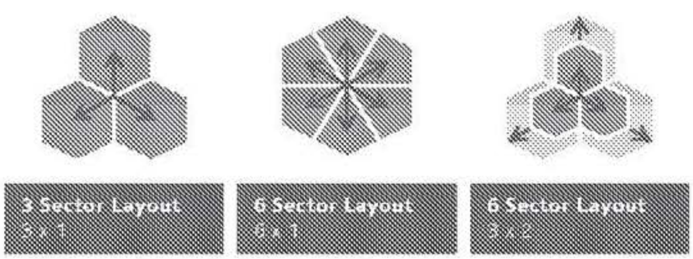

Figure 6. Different sectorization options

Many operators are facing challenges such as lack of new site locations, operating frequencies with limited coverage and performance and ever-growing demand for a high-quality end-user experience. With

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multi-sectorization, operators can improve their rollout and meet the challenge of traffic growth by providing more coverage and more capacity simultaneously. They can also improve end-user service quality without having to invest heavily in new base station sites. Deploying multi-sectorization will also reduce the need for new macro sites.

Nokia Networks provides site solutions for multi-sectorization, increasing mobile broadband downlink capacity and coverage. Detailed studies of real vertical sectorization deployment in suburban and urban environments show a significant performance gain, as shown in Figure 7.

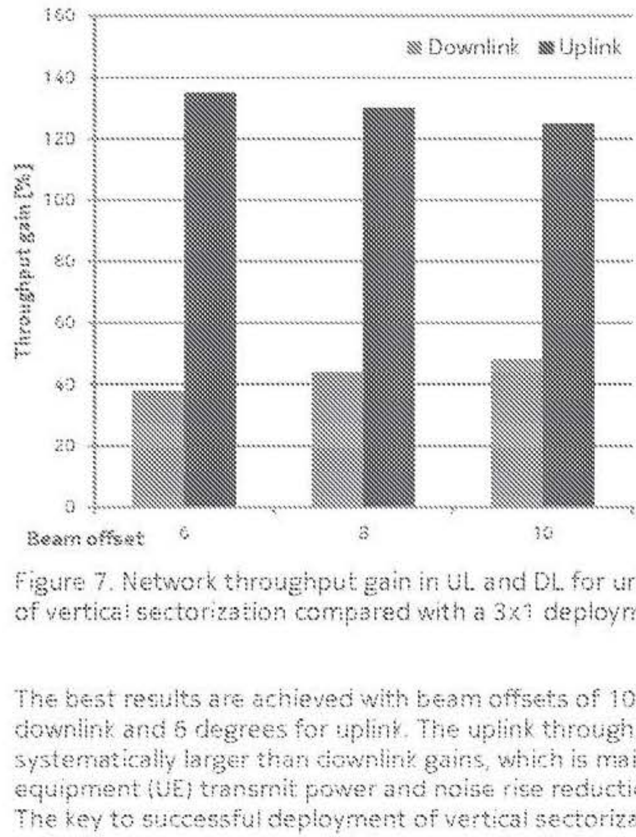

Figure 7. Network throughput gain in UL and DL for urban deployment of vertical sectorization compared with a 3x1 deployment.

The best results are achieved with beam offsets of 10 degrees for downlink and 6 degrees for uplink. The uplink throughput gains are systematically larger than downlink gains, which is mainly due to user equipment (UE) transmit power and noise rise reduction in the uplink. The key to successful deployment of vertical sectorization is to ensure a significant coverage area of the inner cell, which has favorable interference conditions and can significantly boost the overall network capacity. Another important deployment case for AAS is dense urban high rise deployments, where antennas are deployed to cover specific buildings. Here, AAS can be configured to cover the building of interest, minimizing interference by aiming the antenna only towards the building.

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3.5 GHz spectrum for urban deployment

New spectrum has been identified by ITU in the 3.4-3.6 GHz band for mobile communications. The 3.5 GHz spectrum is ideal for small cell deployment as it has a higher pathloss slope and thus minimizes interference with surrounding cells. Furthermore, the 3.5 GHz spectrum also has great potential for urban macro cells deployment, see Figure 8.

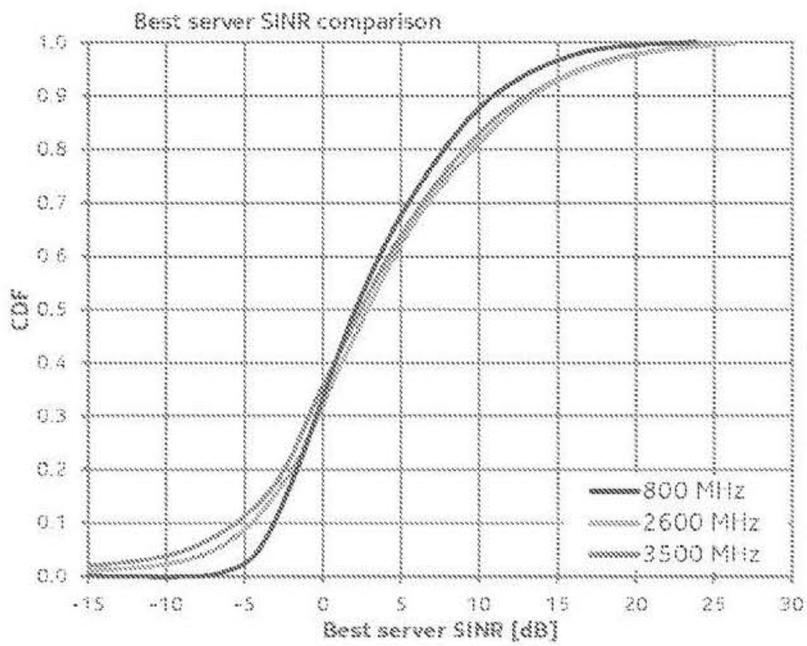

Figure 8. Signal to interference and noise ratio (SINR) for dense urban macro cell deployment

The signal to interference and noise ratio characteristics at 2.6 GHz and 3.5 GHz are very similar - the average SINR is ~0.6 dB lower at 3.5 GHz compared to 2.6 GHz, with a 5th percentile SINR ~1.5 dB lower at 3.5 GHz compared to 2.6 GHz. The 800 MHz provides better coverage because 5th percentile SINR is ~2 dB higher compared to 2.6 GHz, which makes 800 MHz ideal for the coverage layer in both rural and urban environments.

Recommendations

The macro network still has great potential for improving both network coverage and capacity. Recommended upgrades are summarized in Table 1.

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Table 1. Macro cell deployment recommendations

Macro cell extensions	Recommendations	Benefit
Tilt optimization	Antenna tilt should be optimized based on the current deployment. This is one of the most cost-efficient ways of optimizing the macro network.	★★★★
Multi carrier	Refarm spectrum for improved coverage. Use <1GHz bands for MBB coverage and higher bands for MBB capacity.	★★★★
Sectorization	Horizontal and vertical sectorization increases both coverage and capacity without macro site densification and provide a cost-efficient upgrade of the network.	★★★★

These enhancements to macro cell deployment will delay the need to deploy small cells in large volume.

Outdoor Small Cell Densification

When traffic increases, the capacity of macro cell networks can be increased by the methods explained in the previous chapter. Macro cell evolution may still not be sufficient to provide the required improvements in capacity, coverage and quality of experience. Adding more macro sites is expensive, and it may be more cost-effective to deploy small cells to add capacity with limited spectrum and non-uniform traffic demand in hot zones/spots.

Macro vs. micro cells deployment

Figure 9 shows an example of an upgrade to a suburban North American network, with a deployment of additional LTE macro cells on the left plot and LTE pico cells on the right plot. The example compares the number of new macro cells the operator would need to deploy with the number of pico cells. The most efficient deployment of micro cell versus additional macro carriers depends on the spectrum availability and traffic density.

In this case study, we have four existing macro sites with three sectors each (12 cells). To serve three times today's traffic, we could add five new macro sites (15 sectors/cells) or 66 new pico cells (average of ~5 per macro sector) to provide the same network performance.

For dense urban environment where mobile broadband capacity is of greater importance than coverage, the ratio of new pico cells to macro cells will be lower, as the pico cell utilization will be higher.

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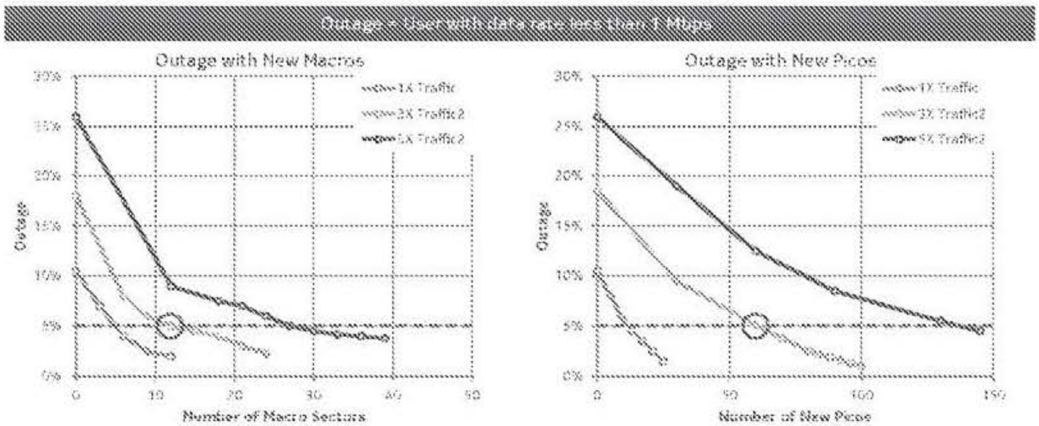

Figure 9. Deployment of macro cells vs. pico cells to achieve similar network performance

In-band versus out-band deployment

When deploying small cells, MNO need to decide which spectrum to utilize for small cells - shared spectrum with macro cells or dedicated spectrum for the small cells. Initially it will be an advantage to deploy the small cells in the same spectrum as the macro cells, as the mobility and continuous coverage will be in place due to the macro overlay network. However, as the traffic grows, interference between the small cells and the macro cells will reduce performance on both layers. Therefore, operators should either introduce interference coordination between the layers or split the spectrum into dedicated groups of spectrum that allow the minimum user data rates required by the end users.

Figure 10 shows an example of North American dense urban deployment of pico cells using two different spectrum options - shared in-band spectrum and dedicated out-band spectrum.

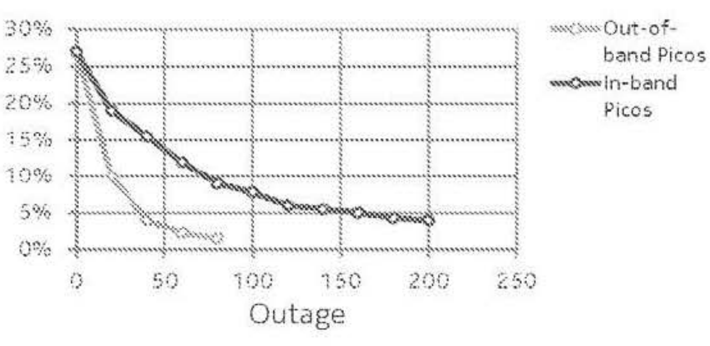

Figure 10. Deployment of small cells in shared spectrum and dedicated spectrum

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To reach an outage of 5%, only around a third of the small cells would be needed to provide the same capacity. We see a breakeven point of in-band vs. out-of-band deployment of around two micro cells per macro cell depending on the traffic load. An in-band solution is more attractive, with a lower number of micro cells. On the other hand, out-of-band performs better with a high micro cell density. The in-band deployment increases network capacity and coverage and is recommended if spectrum is limited and macro networks are fully developed. The cost efficiency is lower than with out-of-band micros. The typical evolution is to start with in-band micro cells. When the micro cell density increases and it can carry enough traffic, the frequency could be fully dedicated to micro/pico cells.

TX power recommendation for micro cell deployment

The larger the coverage area of a micro cell, the more user equipment it attracts. The dominance area depends on the transmission (TX) power, the spectrum used and the micro cell selection parameters. For high traffic volumes the micro cells may become congested. In this case, it is better to provide an additional micro-carrier than to reduce the micro TX power. Reducing TX power in outdoor micro cells together with increasing data rates raises the probability of coverage holes.

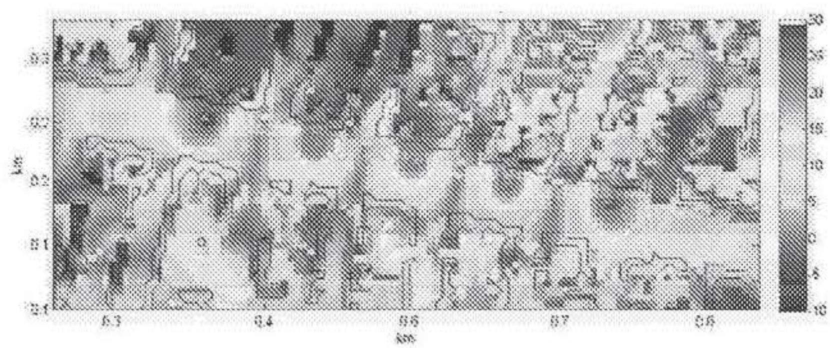

Figure 11. Example of 37 dBm micro cell coverage area in a dense urban deployment with 80 m ISD.

Figure 11 shows a deployment of five micro cells along a shopping street in a dense urban area with 80m Inter-site Distance (ISD). Each cell transmits with 37dBm and provides blanket coverage both indoors and outdoors. For denser or hotspot deployment, 30dBm provides sufficient coverage. Furthermore, bias in cell selection can be used if microcell shrinking is desired.

Small cell deployment via remote radio heads (RRH)

Deploying small low power cells via remote radio heads (RRH) is a simple way to expand the coverage and capacity using existing macro sites. The front haul connection to a RRH requires high bandwidth and low

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latency. To accommodate this, a typical connection of RRH is done via dark fiber. This limits the deployment to markets with very deep fiber penetration (only 8 countries in the world have over10% fiber to building penetrations) and even in these countries, fibers rarely reaches light poles and other poles where most small cells will be deployed.

The majority of small cell functionality for the RRH, such as baseband processing and higher layer functions, are implemented in the macro (including radio resource management). Thus, there will be a cluster of macro cells and a set of RRH open opportunities for advanced multi-cell RRM such as Coordinated Multi-Point (CoMP) transmission/reception and inter-site carrier aggregation. CoMP enables the UE (depending on its location) to receive signals from multiple cell sites, while the UE's transmissions may be received at multiple cell sites regardless of the system load. If the transmissions from the multiple cell sites are coordinated for downlink, the performance can be increased significantly. CoMP can be simple, such as techniques that focus on interference avoidance, or more complex, as in the case where the same data is transmitted from multiple cell sites. For uplink, the system can take advantage of reception at multiple cell sites to significantly improve the link performance, for example through techniques such as interference cancellation.

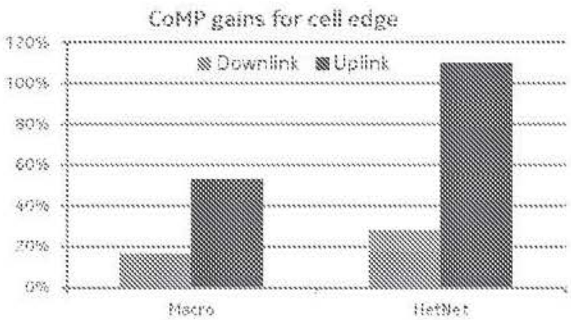

Figure 12. CoMP gains for macro and HetNet deployment (Intra site Joint Transmission/Joint Processing)

Figure 12 shows an example of CoMP gains with RRH configured as macro cells (high power) and small cells (low power). The CoMP gains are higher in a HetNet than in a macro only scenario because of larger power differences between macro and small cells. CoMP gains are higher in uplink than in downlink. The uplink CoMP gains require only LTE Rel. 8 UEs, while downlink CoMP requires Rel. 11 UEs and thus cannot be fully utilized before significant penetration of Rel. 11 UE is achieved in the network.

UL vs. DL traffic load driving network upgrade

Some networks are Downlink (DL) performance limited while others are Uplink (UL) performance limited. The ratio of UL/DL traffic load is ~1:5.

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The ideal network upgrade depends on which link is currently limiting the performance. UL performance limitations often result from a tight link budget. In this case, additional macro carriers will not improve the performance, micro cell deployment at the cell edges having the largest impact.

In contrast, a DL limited network will immediately gain from the addition of more macro carriers, since a significant part of the UL traffic comes from smartphone signaling. Once traffic grows further, UL signaling overhead will not grow at the same rate as data traffic. The ratio of UL signaling and downlink traffic will decrease as a result and growth will arise mainly from DL traffic growth, while the UL performance improves.

Zone deployment of small cells

Deploying small outdoor cells in clusters can further enhance performance and TCO and significantly relax the backhaul requirement for the small cells. This is key, as most small cells will be deployed at street level where good fixed line connections are hard to come by or extremely costly to install.

A zone topology deploying small cells is composed of two key elements – access points and a zone controller. The zone deployment enables operators to deliver wireless broadband access outdoors at street level using clusters of coordinated small cells or indoors in hot zones like shopping malls or airports, see Figure 13.

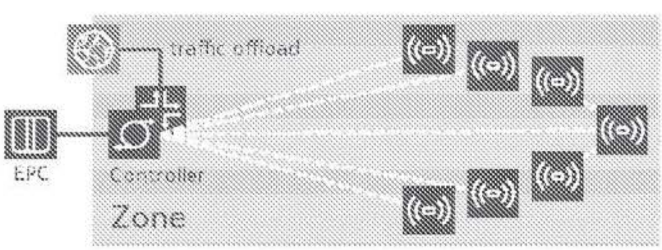

Figure 13. Small Cell Zone architecture and deployment

The zone architecture can use wireless Non Line of Sight (NLOS) backhaul to cost-effectively deliver outdoor street-level deployments and place the access point deep into a hot zone for better performance and requires only one connection to the Evolved Packet Core (EPC) for up to 100 Access Points (AP). The radio deployment aspects of the access points remains unchanged but the backhaul for the zone deployment significantly reduces the TCO. Even if the same spectrum is used for the macro network and zone deployed cells, the interference is reduced from the macro network, improving the user experience. Furthermore, it hides the AP architecture from the macro network and thus eases interworking and management. Thanks to IP offloading and zone level mobility, it significantly reduces the EPC cost of large small

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cell deployments. Finally, with up to 100 AP being managed as one entity, plus SON for HetNet innovation, the impact on operations and maintenance and complexity are significantly reduced.

Recommendations

Outdoor small cells provide cost efficient ways to improve coverage and capacity. The summary of the outdoor small cell recommendation can be seen in Table 2.

Table 2. Cost-efficient recommendation for outdoor small cell deployment

Offload technology	Recommendations	Benefit
Micro cell	Cost efficient means to increase network capacity and coverage. In-band deployment if spectrum is limited, otherwise out-band deployment. Allows for feature parity with macro cells.	★☆☆☆
Pico cell	Cost efficient means to increase network capacity and coverage. Allows for feature parity with macro cells.	★☆☆☆
Low power RRH	Cost efficient means to increase network capacity and coverage. Allows for further improvement with for example CoMP but limited wide scale use due to requirement for fiber	★☆★☆

Indoor Small Cell Deployment

In high-traffic density areas the recommended first step is to enhance macro layer capacity with an upgrade and then to deploy outdoor micro/pico cells. Furthermore, in dense indoor traffic hotspots such as train stations, airports, shopping malls or enterprise buildings, indoor cells provide a very viable coverage solution.

Distributed Antenna Systems (DAS)

A Distributed Antenna System (DAS) is the distribution of cellular RF to a network of antennas within a building to provide cellular coverage. The DAS distributes RF from a centralized radio source throughout the building using a network of RF cabling, splitters, couplers and antennas, fiber optic cabling and RF repeaters.

The aim is to create an indoor coverage layer seamlessly integrated with the macro layer and handling all voice and data traffic internal to the building, offering better quality and user experience. This indoor layer will form an underlay to the macro layer, offloading the much needed capacity from the macro layer and creating potential revenue for the operator. The benefit of DAS comes from its ability to support all operator services (neutrality) using the same system and to be technology agnostic. DAS upfront costs are typically high but offset by

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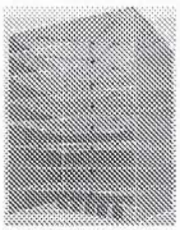
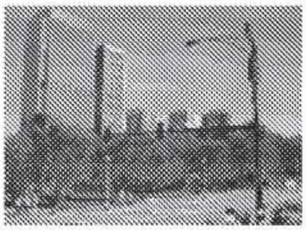
the ability to split the cost amongst operators, making it more suited for large and very large buildings where the high expense can be amortized across a large number of users. Following installation DAS quite rigid architecture suffer from complex, costly capacity scaling.



Indoor DAS



Outdoor DAS

Figure 14. Distributed Antenna Systems (DAS)

Distributed Antenna System (DAS) solutions can be classified as passive, active, or hybrid systems.

- **Passive DAS:** In passive systems, the wireless signal from the RF source is distributed to the antennas for transmission without any amplification through a series of passive components.
- **Active DAS:** In active DAS, the RF signal from a source is converted to a digital signal for transmission over fiber optics or cable. It is fed to multiple remote units that convert the signal back to an RF signal for transmission through an antenna.
- **Hybrid DAS:** A hybrid DAS system is a combination of passive and active systems. In a hybrid DAS system, fiber optic or CAT5 cable is still used to connect the head end (master unit) to the remote units. However, passive DAS is used for distributing the RF to the antennas from the remote units.

Indoor coverage and capacity complement by femto cells and Wi-Fi

The indoor offload potential is quite significant, since a large percentage of global wireless data traffic are generated indoors and most if not all smartphones and laptops are equipped with Wi-Fi connectivity. The indoor offload will connect users to the nearest connectivity node, reducing interference and transmission power, increasing capacity and reducing battery consumption.

Load-based traffic steering between the macro, micro, pico clusters and Wi-Fi/femto layers will be needed in order to use the available spectrum efficiently. Furthermore, automatic authentication is needed for Wi-Fi offload to reach its full potential, because manual authentication will prevent some users from going through the registration process.

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Figure 15 shows an example of indoor data offloading to Wi-Fi cells in a macro and micro overlaid network. It can be seen that the number of users getting less than 10Mb/s is significantly reduced from 12% to 5% with only 200 Wi-Fi cells in a 1 km² area. An alternative would be to deploy more indoor Wi-Fi cells and fewer outdoor cells as shown with an example of 1700 Wi-Fi and 100 micro cells. The split between outdoor and indoor cells depends on which one is the most cost efficient solution. It has been shown that similar performance can be achieved by deploying indoor femto cells.

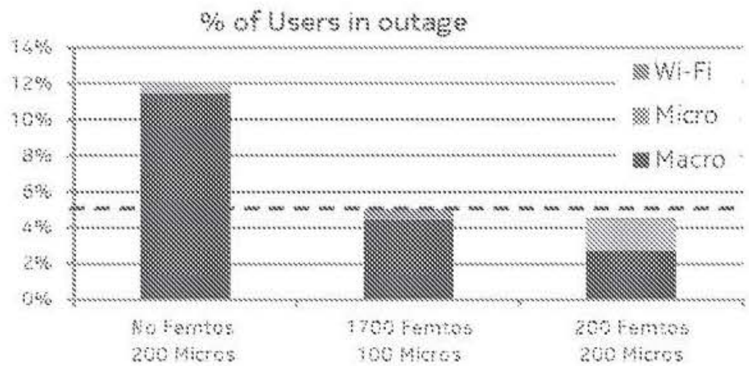

Figure 15. Example of indoor offload via Wi-Fi cells in a dense urban area with 20 macro sites and 200 micro cells.

The deployment of femto cells in indoor locations faces the same challenges as outdoor small cell deployments apart from the interference management benefits for natural shielding provided by the structure of the buildings. In-band deployment is the default option due to operators having limited spectrum resources. Femto cells do not typically have advanced schedulers as micro/pico BTS and the necessary interfaces to coordinate with macro in order to reduce interference. This makes them more suitable for indoor coverage (natural shielding).Femto cells inability to manage interference means they are not very suited to a high density or large environment that requires very dense deployment or a very large number of cells.

The challenges of femto deployment become even more pronounced when a femto cell is configured with a Closed Subscriber Groups (CSG) identity. A user that is not part of the CSG group will connect to the micro of macro network and experience or cause significant interference problems as normal mobility is overruled by the subscriber group admissions.

The optimum performance will be achieved by configuring all femto cells as Open Subscriber Groups (OSG). However, femto cells provide excellent voice coverage extensions and the low transmission power and building attenuation isolate the femto cells very well from the macro cells.

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Wi-Fi is an important local area technology option for heterogeneous networks, complementing mobile technologies to improve performance for the user as well as improving offload capacity. One of the criteria for Wi-Fi to become a successful part of the mobile network is technologies and procedures that enable efficient traffic steering between cellular and Wi-Fi, a seamless Wi-Fi/cellular access and therefore a better user experience. Such functionalities are supported by Nokia Networks' Smart Wi-Fi solution in a way that is independent of the underlying Wi-Fi networks and the Wi-Fi vendors.

The use of Wi-Fi technology is the preferred means of offloading data from macro cells for users at home or in the office. Smartphones should use Wi-Fi where possible. For public Wi-Fi deployment, careful selection is crucial for effective offload while providing the best user experience. Outdoor Wi-Fi deployment has limited potential where mature macro networks are already installed. It also requires careful planning to limit interference sources from the unlicensed spectrum. Furthermore, many DSL lines are limited to less than 10 Mbps, which is slower than a typical LTE macro cell.

Indoor coverage and capacity with pico cluster

Many indoor public or enterprise areas are evolving into hot zones or are strategically important areas to serve for operators, and a new approach that combines the benefits and simplicity of Wi-Fi with the robustness and guaranteed Quality of Experience (QoE) of 3GPP pico cells will be required. Our studies have shown that, where allowed, high power indoor nodes of 30dBm can reduce the number of cells needed by up to 50% compared to femto indoor cells. Nokia Networks' indoor solutions takes into account the future need for very high cell density with a pico cluster Multi-RAT approach. This provides a solution that can use the installed Ethernet network as backhaul, with aggregation of connected APs and local breakout to limit network impact and provide local routing to enterprise Local Areas Network (LAN) servers if required. For more economical deployments, Self-Optimizing Networks (SON) principles are used to simplify operations and maintenance, in addition to innovative interference management techniques that ensure scalability (low impact/fast deployment of new pico).

Recommendations

Indoor Wi-Fi deployment achieves the lowest cost, lowest energy consumption, and the best network performance in a high-traffic urban environment. Indoor femto cell deployment requires a similar number access points to provide the same performance however, it shares the spectrum with the micro cell layer and can cause interference and is not suitable for very dense, very large deployments.

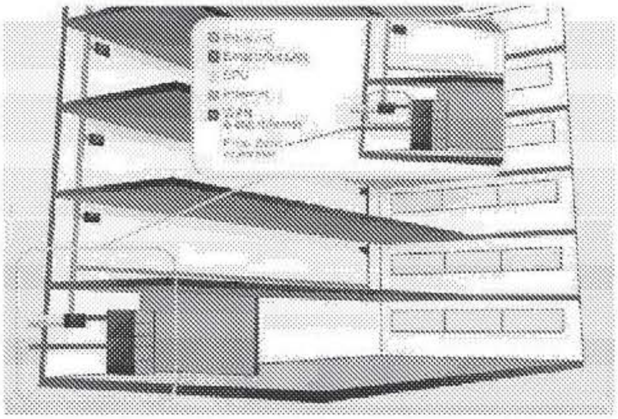

Figure 16. Example pico cluster indoor deployment

Wi-Fi is a good supplement to an installed DAS system to help bring capacity for large indoor venues that require an operator neutral deployment. An LTE pico or pico cluster type solution can be a good complement to an existing DAS system and add significant capacity or boost subscriber experience. Finally, deployment of indoor pico cells can reduce the scale of deployment to provide a cost optimized solution. The summary of the indoor offload recommendation can be seen in Table 3.

Table 3. Cost-efficient indoor offload recommendation in traffic hot spot areas

Offload technology	Recommendations	Benefit
Wi-Fi	Deployment for capacity enhancements, especially in high public indoor traffic areas.	
Femto	Residential deployment of femto cells provides excellent coverage and capacity for voice and data	
Indoor pico	Deployment providing coverage but focused on capacity in indoor public and private hot zones. High number of cells deployed with easy, low impact and fast scalability.	
DAS	Suitable to providing cost-efficient coverage in large buildings and is operator neutral. Less cost-efficient for capacity-driven scenarios and small buildings than Wi-Fi.	

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Cost Considerations

Total Cost of Ownership (TCO) is one of the most important deciding factors when choosing a network deployment path. However, the TCO in each case depends on the operator's current installed base, its spectrum situation and user equipment penetration. The different deployment paths have been analyzed from a TCO perspective to outline the key TCO trends.

The target of a TCO calculation is to bring together all the costs of a technical solution over its lifetime (in this case complete network evolution scenarios over 5 to 10 years) and express them in a single figure. These TCO values can then be compared to discover the best deployment options. For a fair comparison, it is assumed that the different network evolution scenarios perform in the same way and satisfy the same traffic requirements.

Figure 17 shows the TCO normalized with the traffic growth, illustrating that the cost per capacity is continuously decreasing.

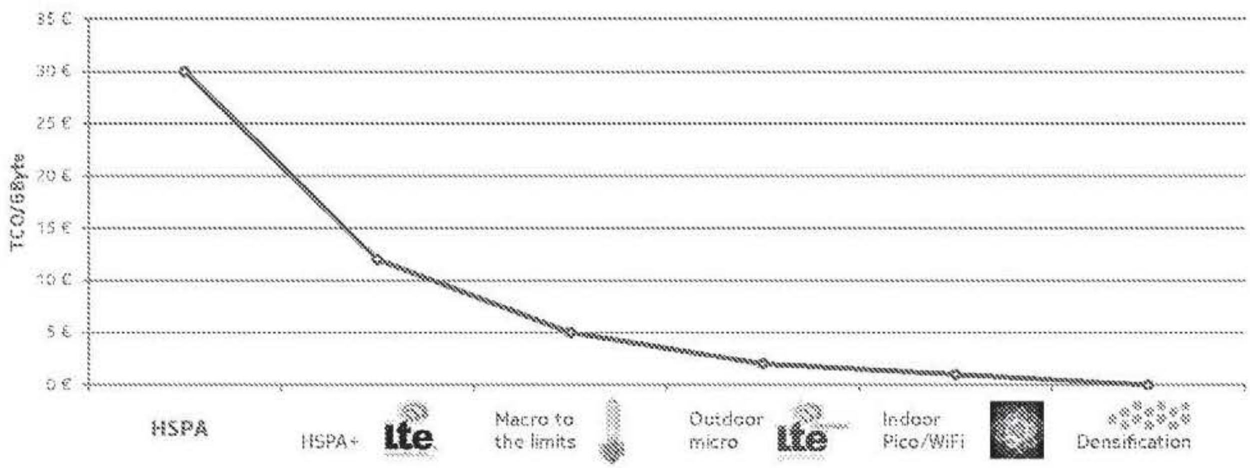

Figure 17. TCO/GB evolution from 2010 toward 2020 based on recommended deployment options (outdoor and indoor deployment may be reverse order)

In this example, cost per GB decreases 100 fold in the same period that the traffic grows 1000 fold. The main reason that cost deceases per GB is that the efficiency of the network evolves continuously and that the small cells carry similar amounts of traffic as the macro cells with a significantly lower cost.

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The deployment options described in this whitepaper have very different cost structures, which are:

Macro network extension

- Tilt optimization is a very cost-efficient method for SINR optimization and thereby increases network capacity. Tilt optimization should always be pursued before any further optimizations.
- Multicarrier: If spectrum is available, adding more carriers to already existing macro sites provides easy and low-cost capacity enhancements. The main cost is in CAPEX and IMPEX (equipment and deployment) – OPEX for the base station increases only slightly (electricity, Operations and Maintenance (O&M), backhaul). However, dedicating spectrum to micro cells can provide an even bigger increase in capacity. Therefore, traffic growth and traffic hot spots play an important role in any site evolution strategy. Furthermore, refarming of spectrum is a cost-efficient way to increase both coverage and capacity. The most cost-efficient approach is to deploy the lower spectrum initially for coverage and deploy the higher spectrum later for macro or micro cells, depending on the traffic density and spectrum availability.

  Sectorization: Sectorization in the vertical or horizontal plane provides a simple yet cost-efficient way to increase capacity in the macro network. The main portion of the cost is CAPEX and IMPEX (equipment, antennas and deployment) but OPEX is also raised owing to higher electricity costs, backhaul and additional site rent for new antennas. Six-sectorization is most efficient for uniform traffic distribution and may not be the best option in localized areas of high traffic or in very dense urban deployments where vertical sectorization by AAS would be more beneficial.

Outdoor small cells

Micro/pico cell deployment is a cost-efficient way of increasing network capacity and coverage. The realization of outdoor small cells by micro base stations means CAPEX for compact micro equipment, but OPEX is very significant for backhaul and site rental. IMPEX for site acquisition and deployment (including a power supply) are also relevant cost factors. Micro cells should be deployed in dedicated spectrum if available. In-band deployment of micro cells may be more expensive for high-traffic-density areas if the spectrum is not already deployed on the macro layer, since both layers would need to be deployed. However, for low/medium traffic-density-areas or already-deployed macro spectrum, in-band deployment is the preferred solution.

Alternatively, small cells can be realized by sharing (or pooling) baseband functions with macro cells and deploying the outdoor small cell Radio Frequency (RF) as a low-power Remote Radio Head (RRH) with

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a dedicated fiber based front haul transport. Low power RRH does not include any dedicated baseband, which can save CAPEX and ease operations and maintenance. However, this is offset by the requirement (and its associated cost) to have dark fiber between the RRH & macro baseband module (front haul connection). Related aspects such as acquisition and rental remain as discussed above.

Outdoor pico cluster

For outdoor hot zones, the future multi-RAT pico cluster based solution can provide a very economical approach compared to other traditional solutions and cell site splitting. A pico cluster solution helps to reduce TCO by simplifying backhaul, managing inter- and intra- layer interference to provide higher performance and limit the amount spectrum planning. The pico cluster provides virtually unlimited scalability, limiting the effect of EPC with local break out and simplifying the operations management and installation.

Indoor offloading

Wi-Fi is always a low-cost supplement to macro and micro cell deployments, since the spectrum is freely available. However, the cost of Wi-Fi depends on the particular backhaul and site acquisition. Wi-Fi and femto cells have very similar TCO performance, with similar CAPEX and almost identical installation and operational costs.

Wi-Fi and femto cells offer large benefits for residential and office installations, while public installations should be based on the traffic density and the available spectrum. The underlying assumption for residential and office scenarios is that backhaul at the deployment locations can be reused without incurring site costs. The cost in offices is assumed to be about four or five times higher than the cost in a residential home.

Future Multi-RAT pico solutions will provide a best of both worlds approach with Wi-Fi and cellular support, and a very cost-effective and scalable solution for indoor coverage and capacity deployments.

Recommendations

The financial impact of the deployment options mentioned was investigated in different real-network scenarios with operators. Although the conditions in different networks vary quite significantly, some general results and recommendations could be derived. The preferred deployment solution from both a performance and cost perspective is a combination of a perfect macro cell deployment for coverage and high mobility users, outdoor micro cell deployment for dense traffic areas and indoor offload for extremely dense traffic areas with low mobility. The recommendations are summarized in Figure 18.

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Figure 18. Deployment cost considerations

Small Cell Evolution Outlook

As part of 3GPP Release 13, a new activity has been started using unlicensed spectrum with LTE alongside licensed spectrum. This is known in 3GPP as License Assisted Access (LAA). This would allow operators to benefit from the additional capacity available from the unlicensed spectrum, particularly in hotspots and corporate environments. With LAA, the extra spectrum resource, especially on the 5 GHz frequency band, can complement licensed band LTE operation.

LTE operation on the unlicensed band is built on top of LTE-Advanced carrier aggregation, which has been deployed commercially since 2013. The simplest form of LTE-Unlicensed would be to use the unlicensed band with downlink only carrier aggregation, while the uplink would be in line with 3GPP carrier aggregation principles, as illustrated in Figure 19. This is similar to the first phase LTE-Advanced carrier aggregation in commercial networks which have started with downlink only aggregation. The primary cell, which ensures the connection is maintained, is always located on the licensed band carrier.

When operating with downlink only on the unlicensed band (supplemental downlink), the LTE eNodeB can perform most of the necessary operations to ensure reliable communications, including checking whether the intended unlicensed channel is free from other use.

The LTE eNodeB should aim to select a channel that does not have another network operating on it with a high interference level, but rather select a channel that is either free or only slightly loaded. Having

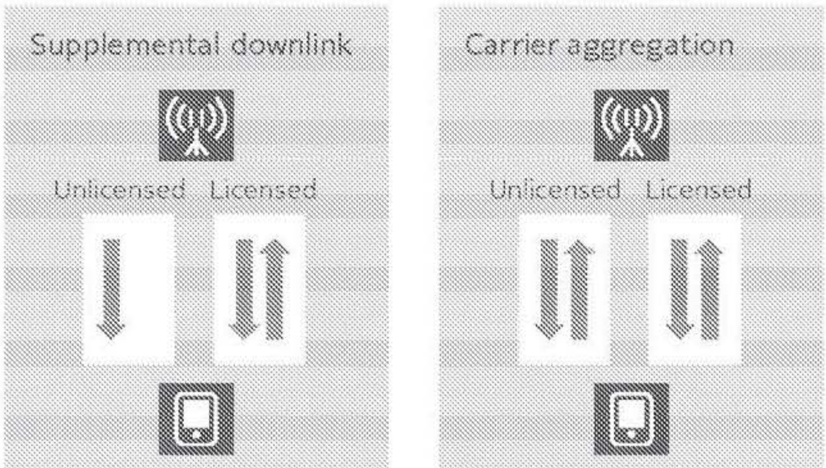

Figure 19. LTE LAA operation modes.

selected the channel, the LBT operation must be performed before transmission is possible, as well as the other necessary procedures in-line with the unlicensed band regulation.

The LTE terminal capable of operating on the unlicensed band needs to be able to make the necessary measurements to support unlicensed band operation, including providing feedback when the terminal is in the coverage area of a LTE eNodeB transmitting with the unlicensed spectrum. Once the connection is activated to allow use on the unlicensed band, the existing Channel Quality Information (CQI) feedback will allow the eNodeB to determine what kind of quality could be achieved on the unlicensed band compared to the licensed band. The downlink only mode is particularly suited for situations where data volumes are dominated by downlink traffic.

The uplink transmission (full TDD operation) from a terminal operating on the unlicensed band requires more features, both in the terminal as well as in the LTE eNodeB, compared to the existing licensed band operation. These extra features are needed to meet the specific requirements of transmission on the unlicensed band, including enabling the LBT feature and radar detection in the terminal side. While in the downlink only mode, these features are needed only on the eNodeB side. Depending on the progress of the 3GPP work, the specification support for LAA may be phased in such a way that only downlink aggregation with 5 GHz band will supported in Release 13, with Release 14 supporting the full TDD operation. However, the current study in 3GPP is addressing both downlink only and full TDD operation.

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Nokia Networks supports operators

Nokia Networks supports operators as they wrestle with the increasing complexities of their evolving networks. We provide smart and unified heterogeneous networks. All network RATs and layers can be viewed as a logically unified network with automated management via the award winning Nokia Networks' SON Solution, known as iSON. This provides seamless interworking and an uncompromising quality of experience for end users - even in a multi-vendor environment.

In other words, Nokia Networks provides solutions for both coverage and capacity. This is a unified approach with services that delivers most optimized Het Net solutions for all use cases, enabling operators to serve the growing demand for mobile data while keeping costs firmly under control.

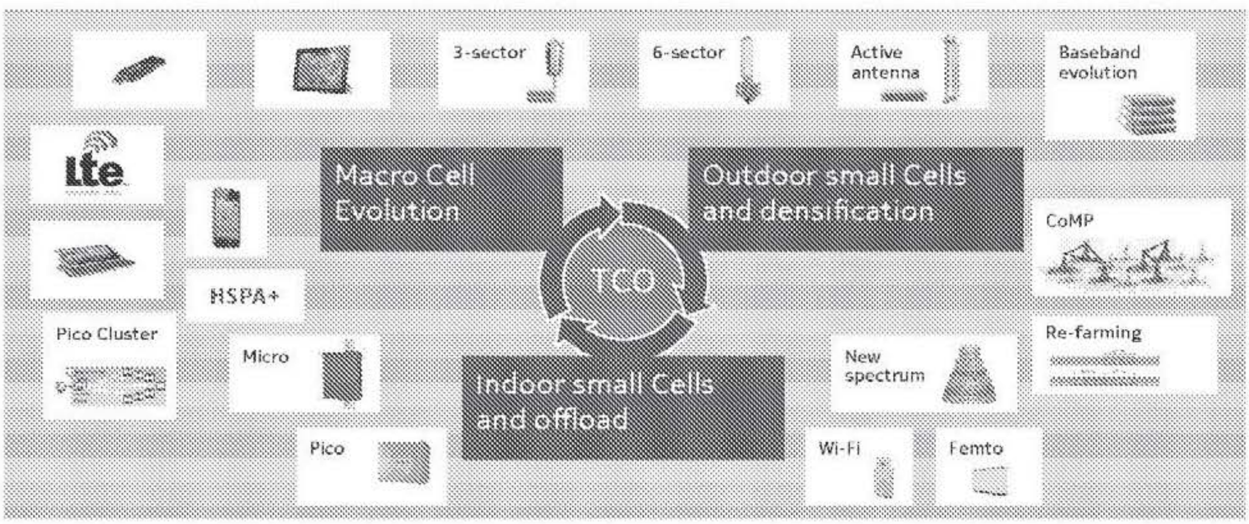

Figure 20. Unified Heterogeneous Networks

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EXHIBIT SEPARATOR PAGE

Don't worry – Mobile broadband is profitable

Following the success of mobile broadband as a service, traffic shows explosive growth. But is it profitable? Dimensioning networks and **figuring out the right price** and packaging have worried some operators. A cost-benefit analysis based on **real operator cases** reveals that mobile broadband is, **in fact**, very profitable.

▶ RECENT REPORTS (from Yankee Group and Heavy Reading) warn operators to be careful of the traps they may face when calculating business cases. At the same time, an increasing number of operators are betting heavily on mobile broadband and positioning it as an alternative to DSL or cable. These operators are seeing tremendous subscriber growth, reaching typically 3 percent – even as high as 5 percent – of the population after two or fewer years of offering the service.

Ericsson, after more than two years of research in close cooperation with 18 operators, has come to a clear conclusion: Mobile broadband business cases show high profit margins, even if the operator is only a pure bit-pipe provider catering to the needs of subscribers using computers.

Here is a snapshot of a cost-benefit analysis based on real and forecasted costs and revenues. (*see graph 1*)

This analysis is made as an investment case, meaning that any costs that occurred prior to the decision to launch mobile broadband are considered to be sunk costs. The result, even after only a few years and with good but not aggressive growth, shows margins in line with or above what operators typically generate today. The conclusion at this stage is that mobile broadband provides a great addition to any operator's business, and can match and compete effectively with DSL.

To substantiate this, we must look at what costs a DSL operator may have. The typical cost per subscriber per month for the unbundling fee can vary by EUR 5–10 (plus equipment). It can go up to EUR 15–30 in a wholesale (bitstream) situation for fiber and VDSL. For an operator owning the copper lines (assuming all equipment is written off), the opex per subscriber per month ranges from EUR 3–5 in urban areas and rises to EUR 6–10 in rural areas, depending on the quality of the copper network.

The comparable costs for mobile broadband are the network opex and capex. Adding the cost for the sites, assuming average traffic of 2GB per subscriber per month, of which 8 percent at busy hour, the network cost comes to around EUR 1.,5–2 per subscriber in a suburban or rural area if the network is reasonably well utilized. In a network where the operator already has sites available, from a 2G network, and in an urban area with higher utilization, the equivalent network cost per subscriber is below EUR 1.

How we calculated

To clarify our method, let's start with a cost analysis for just a radio base station.

Base stations account for a substantial part of an operator's mobile broadband costs, because of the large number deployed. A typical radio base station (NodeB) in an HSPA mobile network, offering 7.2Mbps, with a three-sector configuration and a cell capacity of approximately 4Mbps (3×4 Mbps totaling 12Mbps), costs up to EUR 40,000. This investment is depreciated over 5–10 years.

Most people look at mobile broadband production cost in terms of cost per gigabyte (GB), and sometimes as cost per subscriber, as we did in the DSL comparison. Let's start with the GB cost to see what an operator can get out of one NodeB. In this calculation we leave out site acquisition/build, which is typically depreciated over 15–20 years and only has a small impact on the result, although it represents a large investment. Some basic assumptions are:

- At 1Mbps it is possible to download approximately 300GB in a month (28 days). (1Mb = 125,000 bytes × 86,400 seconds per day.)
- Each subscriber generates an average of 2GB per month.
- Depreciation is five years.
- Cell capacity is 4Mbps (GRAKE2, 16QAM, 10 Codes, and a 500m suburban cell. *Result from Ericsson Radio Network Planning Tool and measurements in real-life networks.*)

With a theoretical maximum of over 43,000GB per year, the production cost using this site would be EUR 0.17 per GB or EUR 0.34 per subscriber per month. No site will ever be utilized to its theoretical maximum, but it could be used up to and above 50 percent. Thus the cost per GB lands at EUR 0.34 and the cost per subscriber at EUR 0.68 per month. Adding the site acquisition/build into the equation with, for example, a EUR 100,000 investment depreciated over 20 years results in around EUR 0.55 per GB. A more loaded site with a 3×2 configuration brings this cost down to around EUR 0.37 per GB. A shared 2G/3G site with a 3×2 configuration costs around EUR 0.26 per GB.

If we do the same type of calculation for the equivalent of a NodeB in a DSL network, namely the DSLAM, the result is as follows: Assuming a price of around EUR 20,000 and an existing site in a suburban scenario with an average speed of around 8 Mbps, the price per GB is around EUR 0.27. The opex related to maintaining the copper lines will of course add to this cost and adds another EUR 0.25–0.30 if we assume the cost to be shared with voice (POTS) and an average consumption of 10GB per month.

Traffic distribution in the networks Ericsson is monitoring (some 30 deployed around the world) shows that only a few sites carry most of the traffic. A normal scenario shows around 20 percent of the sites carrying more than 50 percent of total network traffic.

This means that most of the sites deployed in a network, whether for voice or broadband, can be considered "coverage" sites. The number of sites carrying heavy traffic is even lower, perhaps 3–5 percent for broadband. These sites will be the first to require upgrading to "second carrier" or higher modulation schemes to provide better capacity. But they are usually the sites that provide the shortest payback time.

Considering that cost per GB is related to how the nodes are used, the operator's challenge is to make use of available free capacity rather than risk congestion.

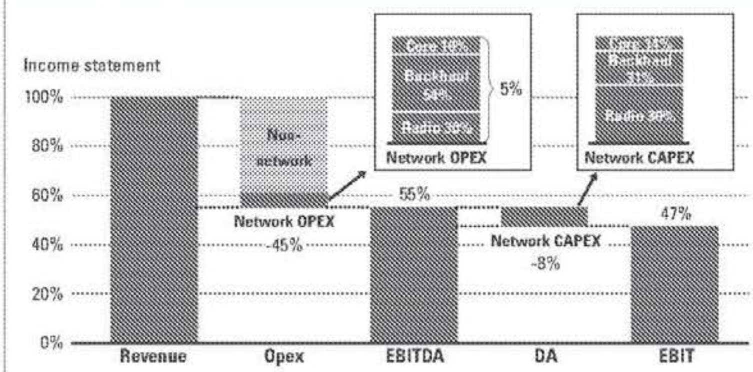
THE IMPORTANCE OF SCALE

When subscriber numbers increase, both traffic and revenue rise. (*see graph 2*) The operator will eventually have to invest in more capacity, in the form of additional carriers, each using 5MHz of the WCDMA spectrum. Each added carrier represents an investment. Because these investments are driven by traffic from more subscribers, there is, of course, a correlation to revenue.

That makes the ability to improve cost-efficiency important; otherwise, margins would slowly deteriorate as users demand more capacity and tariffs are lowered. Meeting this requirement is what the technical evolution is all about. Consider a given site configuration, starting at 7.2Mbps and going up to 21Mbps using HSPA Evolution, which adds a cost of around 10–15 percent. At the same time, capacity increase is around 70 percent. Going to even higher speeds using dual carriers and other features improves the site's efficiency.

Let's look at a site with a cell radius of 400m using 10Mhz spectrum and MIMO

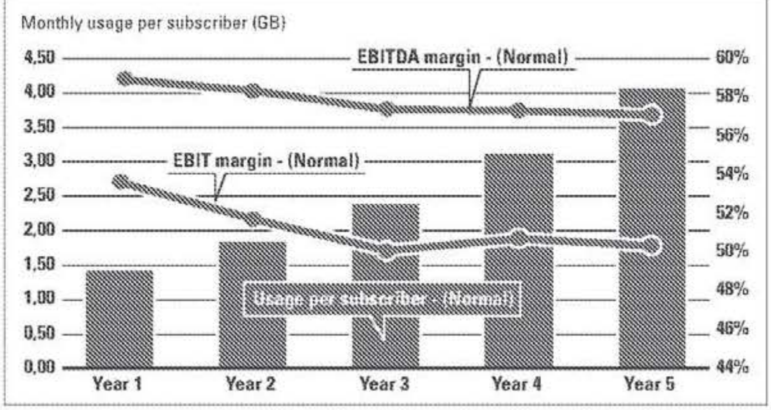
[graph 1]
Profitability of mobile broadband



Source: Ericsson Analysis; BNET Sales Development Mobile Broadband Team

Assuming 4 percent of the population has been reached four years after launch, with an ARPU of EUR 20 using unlimited flat rate and average traffic per subscriber of 2GB per month. All costs related to mobile broadband are included in the case. The revenue bar is aggregated revenue based on subscribers times ARPU (EUR 20). Non-network costs include terminal subsidies, marketing, customer care, and IS/IT. Network opex includes power consumption and support for related equipment. Capex includes any expansions or additions required to support HSPA depreciated over 8 years for hardware and 3 years for software.

[graph 2]
Projected 30 percent YoY growth



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In the long run, ***unlimited flat rate*** with a fair-use clause is potentially cheaper and more profitable for the operator than bucket plans.

(2GB/month, 8 percent busy hour). It has a capability to handle over 4000 subscribers at 50 percent load. That cell radius equals approximately ½ km² and can be compared to New York with around 25,000 people per km². Assuming an operator gets 30 percent of the total population, that equals 3,750 subscribers per site.

These examples show only the cost per GB for a NodeB. But if we look at the entire HSPA network (reasonably well utilized, with the cost of site acquisition and build included), we see that all costs, including the radio network controller (RNC) and the core nodes SGSN and GGSN, typically represent a small part of the total cost per GB. The mobile backhaul and optical transmission in the core cost less than EUR 0.1 per GB compared to a 3×2 NodeB at EUR 0.37 per GB. (*see graph 3*)

Real-life business cases

Simple calculations don't tell the full story of a real business, but they provide a good indicator. Let's turn our focus to real-life cases, based on research in cooperation with established operators from all parts of the world.

Ericsson has developed a tool to make a complete end-to-end analysis, including all aspects relevant to the business case. Even voice and SMS traffic, though not part of mobile broadband, should be considered because they affect overall network dimensions. Mobile broadband must share network capacity with other services, especially the radio bearer, and voice in particular. All operators in our research have a 3G network covering 40–70 percent of their respective populations.

We have noticed that operators often struggle with their own calculations because of difficulties in identifying or allocating costs that are strictly related to mobile broadband.

In our work to produce real business case examples, we have proceeded as follows:

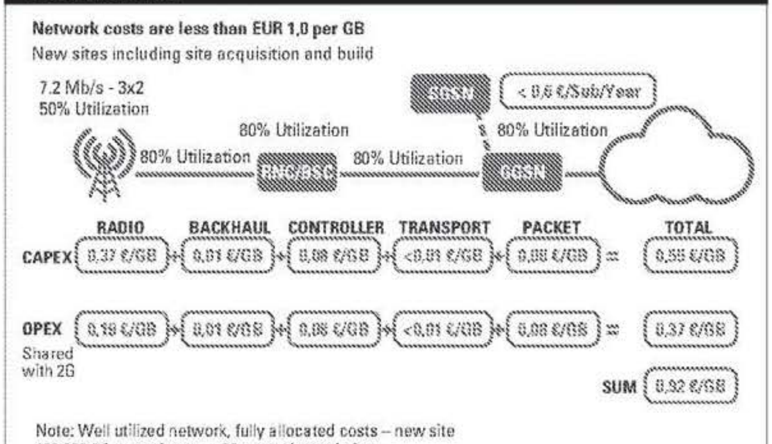
Analysis is based on existing traffic patterns and forecasts, creating a scenario for the next five years. The traffic and subscriber growth scenario determines the capacity required in all nodes including radio and backhaul, and thus drives cost over the five-year scenario. The case includes all non-network costs, such as handset subsidies, marketing, and customer care. Although marketing costs, for example, may be much higher initially, we believe that within three to five years they will stabilize at a level similar to today. Therefore, the non-network costs will be around 40 percent of revenue for a Western world operator and somewhat lower in low-ARPU regions.

Analyzing a static network won't satisfy an operator looking for real-life answers. So we look at key areas where there are question marks.

What would happen, for instance, if traffic per subscriber increased dramatically? Not the statistical average, which can increase because a few users generate huge amounts of data, such as when using peer-to-peer; but rather a traffic increase that an operator must consider when dimensioning the network. We also investigate what would happen if an operator moved away from E1/T1 (backhaul on leased lines) and used microwave links instead. Finally we consider what effects that variations in subscriber uptake could have on the business case.

The graph (*see graph 4*) shows how an increase of traffic per subscriber affects profitability, assuming all other things are equal. We conclude that, within limits, we can maintain strong profitability even if

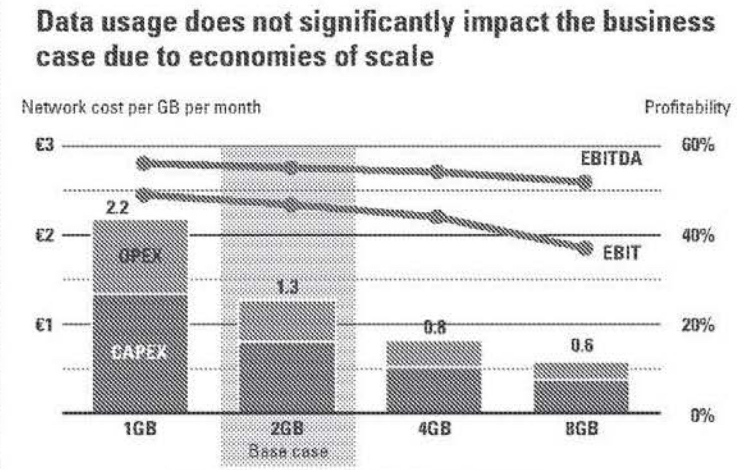
[graph 3]
HSPA network costs



Note: Well utilized network, fully allocated costs – new site 100,000 € for passive part, 20 years depreciation traffic increases drastically. In the scenarios modeled with operators, shown in the graph, we have calculated with network capabilities up to 21Mbps, being introduced in some networks during 2009. But we need to remember that technology is evolving very fast. When allowing the network to evolve all the way into a five-year scenario and assuming speeds up to 56Mbps, we have the tools we need to keep up with demand and remain profitable.

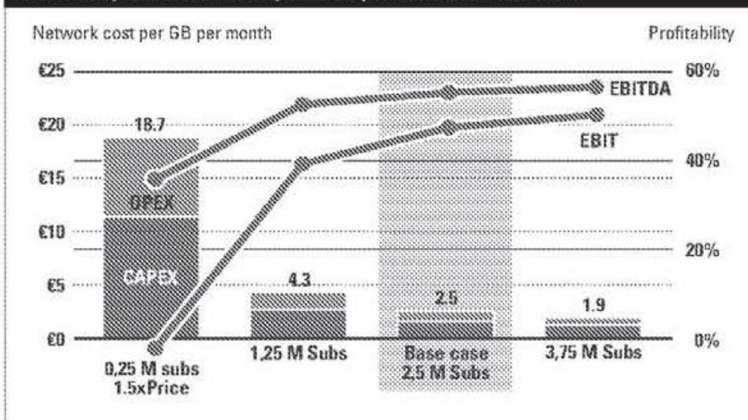
The most important element of profitability is subscribers paying for the service. The graph shows how profitability drops unless enough subscribers are added (*see graph 5*). Many operators still have a long way to go before they have enough subscribers to be profitable. At the same time, we do see a few operators who, after two years, have reached a population penetration above what we use in this sensitivity analysis. What still has an effect on the end result for these operators is the amount of nodes that they have built out so far. The population coverage does vary between operators and the prerequisites vary by country. The Nordic countries for example have quite low population density and therefore require more sites per inhabitant than countries with high population density.

[graph 4]
Economies of scale



Source: Ericsson Analysis

[graph 5]
Customer uptake: The driver for profitability due to economies of scale



Source: Ericsson Analysis

Handling the threats

If distribution cost per GB is counted in euro cents, and traffic is not an issue at most of the sites, why do we keep hearing that traffic will kill the networks?

The most common argument is that heavy downloading through file sharing via peer-to-peer applications generates huge amounts of traffic. As a consequence, few operators dare adopt the de facto price model on wireline broadband, namely, unlimited flat rate. Even though this flat rate promotes subscriber uptake and is the easiest pricing for consumers to understand, operators still worry about uncontrolled costs from heavy increases in traffic.

All or most mobile networks today have been running voice, SMS, MMS, and some mobile data traffic. None of these have generated much traffic per subscriber. Revenue growth has been well aligned with traffic growth (and thus traffic cost) per subscriber. Then along came this new service that, compared to SMS, for example, easily generates 10, 100, or even 1000 times more traffic per subscriber. This has triggered a knee-jerk reaction among operators, who think that such a service can't be profitable.

The three applications generating the highest volume on the internet today are peer-to-peer file sharing, web browsing, and video streaming. Peer-to-peer alone accounts for over 60 percent of all household-generated traffic. And with traffic per subscriber increasing at a yearly rate of 30 percent, driven mainly by file sharing, we should look at peer-to-peer for opportunity.

Operators want as many profitable subscribers as possible. This means that investments made in the network are driven by the bulk of subscribers and not by a few heavy users. Ericsson addresses this by introducing traffic-handling prior-

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ity throughout the network, which allows the network itself to manage its resources. The operator must introduce a fair-use clause in the subscriber's contract so it can manage heavy usage intelligently. Most commonly, mobile broadband operators use unconditional throttling today, which means that once the fair-use level is reached, the throughput drops to a predetermined level. Typically, though, these speeds don't allow for meaningful use of the broadband connection.

Traffic-handling priority (*see graph 6*) gives the heavy user a lower priority in the network once the fair-use level is reached. The heavy user experiences a degradation of the service only when competing for resources in a congested situation. But in peer-to-peer, the experienced reduction of the throughput will, over time, be limited. Only in heavily loaded cells does a peer-to-peer user experience serious problems. Those sites would soon be targeted for capacity upgrades since it is normal usage that is creating the congestion.

Traffic-handling priority allows an operator to focus on dimensioning the network for normal usage while still allowing unlimited or "all you can eat" traffic. The consumer gets better overall quality and the comfort of using an unlimited service that does not generate surprises on the bill.

In the long run, unlimited flat rate with a fair-use clause is potentially cheaper and more profitable for the operator than bucket plans. Subscriber uptake aside, we see that bucket size is increasing drastically, driven by competition and as a way means to segment the market. It's probably fair to assume that buckets of 10, 20, or even 50GB already on the market must be fulfilled by the operators. With bucket plans, the traffic volumes for dimensioning the network would continually increase, and the only limitation the operator has is the bucket size. However, the fair-use level for an unlimited flat rate offer may not need to change at all, or at least very little, over time since it does provide an "all you can eat" model. The segmentation is instead achieved through speed and price.

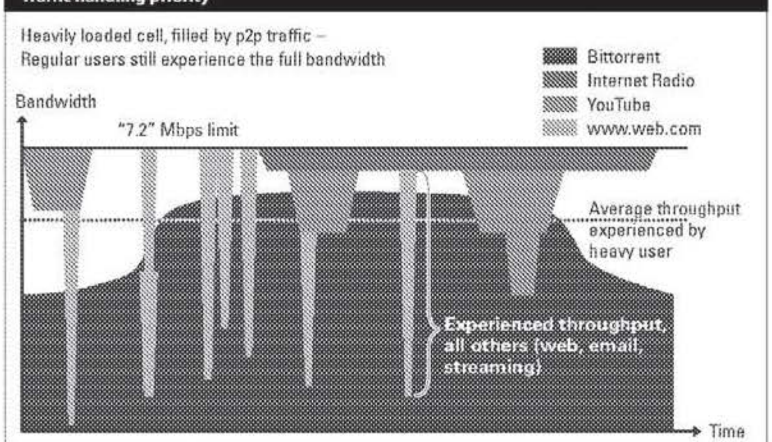
Unlimited flat rate is a complex issue, and it is difficult to predict what will actually happen in a network when this model is applied. Although the model does allow each user to generate as much as they want, other factors influence the outcome. The operator's chosen position in the market determines which subscribers it attracts. This in turn defines the behavior of its subscriber base. Great variations exist between operators in the same market with similar packaging and pricing.

We have based this pricing discussion entirely on PC-based subscribers to prove that there is good profitability even in offering a simple bit pipe. Introducing intelligent management functions in the network allows the operator to handle all sorts of situations, such as separating application streams from each other, or varying traffic – and perhaps pricing – depending on time of day; or giving different priority to smartphone users over PC users; or giving paying mobile-TV viewers a higher priority than "best effort" internet. The possibilities are nearly endless, and it comforts operators to know they exist.

When we add them all together and put them on top of the simple bit pipe, we improve on an already powerful concept that will continue to generate good profit for operators in the future.

And finally, it is nice to get the kind of confirmation we recently received when one of Ericsson's customers reported to us that its current cost per GB for mobile broadband is now down below EUR 2, after only two years of operation.

[graph 6]
Traffic handling priority



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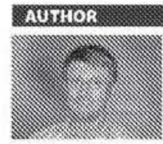

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